MICROSPRINKLER IRRIGATION OF MATURE, RESET, AND YOUNG GRAPEFRUIT (CITRUS PARADISI MACF.) TREES WITH RECLAIMED WASTEWATER

By

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MICROSPRINKLER IRRIGATION OF MATURE, RESET, AND YOUNG GRAPEFRUIT (CITRUS PARADISI MACF.) TREES WITH RECLAIMED WASTEWATER

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Several experiments were conducted on mature, reset and young grapefruit trees to determine the effect of reclaimed wastewater on growth, development and yield in Florida.

An experiment was designed to determine the effects of canal water and reclaimed wastewater on growth and yield of mature 'Redblush' grapefruit (*Citrus paradisi* Macf.) trees. Trees receiving low (23.1 $mm \cdot wk^{-1}$) and moderate (30.7 $mm \cdot wk^{-1}$) levels of reclaimed wastewater had the largest tree canopies, trunk diameters and highest yields. Fruit growth rate, size, juice weight, total soluble solids (TSS), titratable acidity (TA), and TSS:TA ratio were similar among treatments 2 of 3 years. Peel thickness was similar for all treatments.

Leaf boron (B) levels were similar for all reclaimed wastewater treatments, but were lower for the canal water treatment. Heavy metal concentrations in the reclaimed wastewater were low or non-detectable. Similarly, enteric viruses in the effluent were always < 0.003 plaque-forming units per liter. Weed growth increased as irrigation levels increased.

Two field studies were designed to determine the effects of canal water and reclaimed wastewater on reset 'Marsh' grapefruit trees. Tree growth and development was similar for all treatments during the first 3 years after planting. Leaf B levels were significantly higher for trees receiving reclaimed wastewater compared to those receiving canal water, however; no B toxicity was observed. Reclaimed wastewater again increased weed growth compared to the canal water treatment.

Four field studies were designed to determine the effects of well water and reclaimed wastewater at 3 irrigation levels and 3 water and fertilization sources on growth and development of newly planted 'Redblush' grapefruit trees. Trees receiving reclaimed wastewater plus fertigation were more vigorous and larger than trees receiving other treatments and had greater yields in the third year. Trees receiving reclaimed wastewater alone were less vigorous and visually N deficient. Leaf Na and B levels increased in trees receiving reclaimed wastewater, but were below toxic levels.

Reclaimed wastewater irrigation of citrus has several potential advantages, with increased weed growth being the only major disadvantage.

Nevertheless, proper drainage and grove design are necessary when regularly applying reclaimed wastewater to citrus groves.

CHAPTER I

INTRODUCTION

Citrus is the most economically important fruit crop grown in Florida with more than 300,000 ha planted and annual production of 11.1 million tons in 1992-93. (Florida Dept. of Agr., 1992). In recent years increased urbanization and planting of citrus in South Florida has put ever- increasing demands on the water supply. Urbanization also causes problems with efficient and environmentally safe disposal of reclaimed wastewater (Katterman and Day, 1987). Previously, disposal of reclaimed wastewater was into waterways, but passage of the Federal Water Pollution Control Act of 1972 and the Clean Water Act of 1977 discouraged the direct discharge of reclaimed wastewater into surface waters (Gleason et al., 1984). Presently, about 41% of all water in Florida is used for agricultural purposes (Fernold and Patton, 1984) and 34% of this water is used to irrigate citrus (Smajstrla et al., 1992). Irrigation of citrus trees with reclaimed wastewater provides a means of wastewater disposal and a water and nutrient source for citrus trees. However, only about 2% of

growers in Florida are currently using reclaimed wastewater to irrigate citrus groves (Ferguson and Taylor, 1993).

Citrus trees require irrigation in Florida to achieve optimum growth and production (Koo, 1963). The low water holding capacity of Ridge and flatwoods soils makes trees susceptible to drought during periods of low rainfall. Conversely, flatwoods soils are also poorly drained due to the presence of a relatively impermeable subsurface layer which may result in flooding during periods of heavy rainfall. Reclaimed wastewater treatment facilities require the frequent disposal of effluent throughout the year, even at times when citrus trees may not need irrigation. It is important to determine the volume of reclaimed wastewater that can be applied to the grove without causing drought or flooding stress.

Citrus trees in Florida are generally grown on sandy soils of low native fertility, which require fertilization for optimum tree growth and production. Fertilization requirements for citrus trees are well defined for mature and young citrus trees (Ferguson and Davies, 1989; Koo et al., 1984). Reclaimed wastewater contains many essential plant nutrients, especially N, P and K, and irrigation with reclaimed wastewater may have an effect similar to that of frequent fertigation with a dilute concentration of plant nutrients (Neilsen et al., 1989a). Moreover, the use of reclaimed wastewater may reduce or eliminate the need for additional fertilization. In addition, citrus trees irrigated with

reclaimed wastewater may reduce contamination of surface and ground water by taking up plant nutrients contained in reclaimed wastewater.

Reclaimed wastewater also has some potential drawbacks due to the presence of heavy metals, salinity, viruses and bacteria. Heavy metals are typically associated with industrial wastewater and may be detrimental to plant growth and human health; however, non-industrial wastewater generally has low or non-detectable levels. Likewise, elements such as Na, Cl and B in reclaimed wastewater may reduce citrus tree growth if toxic levels occur. In addition, viruses and bacteria present in reclaimed wastewater may pose a potential hazard to workers and consumers. However, the level of heavy metals, salinity, viruses and bacteria vary depending on the location and source of reclaimed wastewater. Vital to the use of reclaimed wastewater is the understanding of how frequently applied reclaimed wastewater influences the growth and development of mature, reset and young citrus trees.

Citrus tree freeze hardiness has been associated with nutrient levels and fertilization rates for many years. Field observations of post-freeze damage from numerous fertilization studies indicate that high N levels increase freeze hardiness of citrus trees. However, no replicated field studies have been conducted to determine the effects of leaf N concentrations on freeze hardiness of young citrus trees throughout the winter.

The results of these experiments may be useful to optimize the use of reclaimed wastewater for mature, reset and young citrus trees, potentially

reducing irrigation and fertilization costs. Determining the potential effects of leaf N levels on young citrus tree freeze hardiness may influence fertilization programs for young trees. This research should enable growers to efficiently and safely use reclaimed wastewater for irrigation of citrus trees and may lead to an increase in reclaimed wastewater use.

CHAPTER II

REVIEW OF THE LITERATURE

Irrigation and fertilization are two important factors essential for achieving optimum citrus tree growth and production. The use of reclaimed wastewater for irrigation of citrus trees is also a potential source of water and nutrients. Reclaimed wastewater provides a consistently available water source, but disposal of large quantities of reclaimed wastewater may cause flooding of the grove during periods of heavy rainfall. Reclaimed wastewater also contains many essential plant nutrients (Berry et al., 1980; Bielorai et al., 1984; Feigin et al., 1984; Neilsen et al., 1989a) which reduce fertilization rates. The uptake of plant nutrients from reclaimed wastewater by citrus trees may prevent surface and/or ground water contamination (Sanderson, 1986). In addition, reclaimed wastewater may be used for freeze protection (McMahan et al., 1989). Potential disadvantages of reclaimed wastewater use include the presence of heavy metals (Kirkham, 1986; Omran et al., 1988), salinity (Basiouny, 1982; Kirkham, 1986) and health risks associated with viruses and bacteria in reclaimed wastewater (Basiouny, 1982; Berry et al., 1980; Brenner et al., 1988;

Gleason et al., 1984; Rose and Gerba, 1991). Understanding the influence of reclaimed wastewater on the growth and development of mature, reset and young citrus trees is critical for the safe and efficient use of reclaimed wastewater.

Irrigation

Irrigation is essential for citrus trees to achieve maximum growth and production (Koo, 1963) and reclaimed wastewater is a potential source of low cost, useable irrigation water. Although Florida's climate is characterized by an average annual rainfall of 1300-1500 mm, rainfall distribution occurs in irregular patterns. Rainfall distribution is characterized by periods of heavy rainfall in the summer and low rainfall during the winter and spring. Low rainfall particularly in the spring combined with the low water holding capacity of most Florida soils requires the use of irrigation to maintain optimum soil moisture levels for tree growth.

The low water holding capacity of Ridge and flatwoods soils makes trees susceptible to drought during periods of low rainfall. The extensive root system of trees on the Ridge provides a large volume of soil with which to obtain available water (Ford, 1952; Reitz and Long, 1955). In contrast, trees on flatwoods soils have a small root system and soil volume (Calvert et al., 1967; Calvert et al., 1981; Ford, 1952; Reitz and Long, 1955; Young, 1951). Graser and Allen (1987) found that transpiration and soil evaporation can deplete

available soil moisture to 75% in 2 days, 50% in 4 days and to less than permanent wilting point in 8 days. However, the upward flux of water from the water table helps meet the water needs of citrus trees grown on flatwoods soils (Graser and Allen, 1987; Obreza and Admire, 1985). In addition, irrigation frequencies and durations are different for citrus trees on flatwoods and Ridge soils. Trees grown on flatwoods soils require more frequent irrigations of shorter duration compared to trees grown on the Ridge (Parsons, 1989).

Mature citrus tree irrigation

The objective of citrus tree irrigation is to obtain maximum production with the least quantity of water (Koo, 1985b). Irrigation of citrus trees increased tree growth and production in many citrus regions (Chilembwe, 1985; Constantin et al., 1975; Hilgeman, 1966; Hilgeman and Sharp 1970; Huberty and Richards, 1954; Koo, 1963; Koo, 1969; Koo, 1975; Koo, 1979; Koo, 1985b; Koo and Sites, 1955; Koo and Smajstrla, 1984; Koo et al., 1974; Levy et al., 1978a; Metochis, 1989; Sites et al., 1951; Wiegand and Swanson, 1982a; Wiegand and Swanson 1982b; Zekri and Parsons, 1989; Ziegler, 1955). The increase in tree size from irrigation may account for the increase in yield (Koo 1969; Levy et al., 1978a; Sites et al., 1951). However, maintaining high soil moisture levels throughout the entire year failed to induce fruit setting and yield proportional to tree size (Boman, 1992; Chilembwe, 1985; Hilgeman and Sharpe, 1970; Koo 1963; Koo, 1969). Metochis (1989) in Cyprus found that

irrigation in excess of the crop requirement had no affect on fruit growth or production of 'Marsh' grapefruit trees. Irrigation is particularly critical during specific times of the year for increasing fruit set (Constantin et al., 1975; Hilgeman and Sharpe, 1970; Koo, 1963; Koo, 1969; Koo and Sites, 1955; Sites et al., 1951) reducing number of 'off bloom' fruit (Koo and Sites, 1955; Reese and Koo, 1976; Sites et al., 1951), increasing fruit size (Hales et al., 1968; Hilgeman, 1966), and reducing fruit drop (Boman, 1992; Koo, 1963; Koo, 1969).

Irrigation of mature citrus trees in Florida is currently recommended at one-third soil water depletion from Jan.-June and two-thirds soil water depletion from July-Dec. Irrigation at these levels provided the most efficient use of water while maintaining tree growth and production (Koo, 1963). In a similar study on the flatwoods, navel orange trees irrigated at 30% soil water depletion throughout the year had similar tree growth and production as trees irrigated at 50% soil water depletion (Boman, 1992). Although high soil moisture content (one-third depletion) throughout the year on flatwoods and Ridge soils increased production, the increased number of irrigations required was not economically justified (Boman, 1992; Koo, 1963).

Fruit quality and development

Irrigation of mature citrus trees affects fruit growth and quality. However, limited information is available on fruit growth and quality of trees irrigated

above optimum levels as would be the case when using reclaimed wastewater. Sites et al. (1951) found that irrigated trees had greater fruit size than fruit from nonirrigated trees. In addition, dry periods 3 months after fruit set decreased fruit size which could not be regained by subsequent irrigation. Hales et al. (1968) found that soil moisture tension correlated with average fruit volume increase and that greater soil moisture tension decreased fruit size. In addition, fruit size is a function of fruit set with less fruit per tree producing larger fruit sizes (Hilgeman, 1966; Hilgeman and Sharpe, 1970). In contrast, Boman (1992) found that fruit weight and fruit size distribution of navel oranges were similar for trees irrigated at 30% or 50% soil water depletion.

Fruit juice content is also influenced by irrigation. Increases in juice content of fruit for irrigated vs. nonirrigated citrus trees are well documented (Bielorai, 1982; Calvert et al., 1967; Koo, 1963; Koo, 1969; Sites et al., 1951). However, Cruse et al. (1982) in Texas found no difference in juice content for trees irrigated at 40% and 60% soil water depletion, but juice content was greater than trees receiving irrigation at 80% soil water depletion. Hilgeman and Sharpe (1970) also found no difference in juice content for trees receiving 1.72 and 1.35 m of water annually, but juice content was greater than for trees irrigated with 0.95 m of water. In Florida, Graser and Allen (1987) found no difference in juice content of trees irrigated at intervals of 2-3 days vs. 14 days, but juice content was significantly greater than nonirrigated trees. Boman (1992) found no difference in juice content for trees irrigated at 30% and 50%

soil water depletion. The results of these irrigation studies clearly indicate that trees receiving irrigation had increased fruit juice content compared to nonirrigated trees. However, irrigation at greater than 50% soil water depletion did not increase fruit juice content.

Peel thickness is primarily influenced by climate (Reuther, 1973) and K levels (Embleton et al., 1973). Increases in peel thickness from irrigation have also been reported by Constantin et al. (1975); however, the increase in peel thickness (10%) was associated with a 30% increase in fruit size. Metochis (1989) in Cyprus found no difference in peel thickness for trees irrigated at 39%, 55% and 63% of pan evaporation. In contrast, Hilgeman and Sharpe (1970) in Arizona found a decrease in peel thickness for trees receiving 1.72 and 1.35 m of water compared to trees receiving 0.95 m of water. Omran et al. (1988) in Egypt reported that peel thickness increased during the years that reclaimed wastewater was used. However, this may be attributed to an increase in soil K levels from long-term use of reclaimed wastewater.

Reductions in fruit total soluble solids (TSS) resulting from irrigation are well documented (Bielorai, 1982; Cruse et al., 1982; Graser and Allen, 1987; Hilgeman and Sharpe, 1970; Koo, 1963; Koo, 1969; Koo, 1985b; Koo and Reese, 1976; Koo and Sites, 1955; Metochis, 1989; Sanchez Blanco et al., 1989; Sites et al., 1951; Ziegler, 1955) with irrigation in the fall affecting TSS more than at other times due to dilution of TSS (Cruse et al., 1982; Koo, 1963; Koo and Sites, 1955). Similarly, Zekri and Koo (1993) found a dilution of TSS

for trees irrigated with reclaimed wastewater which received a larger volume of water than well water irrigated trees. Fruit TSS was similar for navel orange trees irrigated at 30% and 50% soil water depletion (Boman, 1992).

Titratable acidity (TA) generally decreases as levels of irrigation increase (Bielorai, 1982; Cruse et al., 1982; Graser and Allen, 1987; Hilgeman and Sharpe, 1970; Koo, 1963; Koo, 1969; Koo, 1985b; Koo and Sites, 1955; Levy et al., 1978b; Metochis, 1989; Sanchez Blanco et al., 1989; Sites et al., 1951). Zekri and Koo (1993) observed a reduction in fruit TA from reclaimed wastewater irrigation which was applied at higher rates than well water. Koo and Smajstrla (1984) found that fruit TA was similar for 3 of 5 years for trees receiving 0.3 and 0.6 m of water annually. Fruit TA was similar for trees irrigated at 30% soil water depletion compared to 50% for 2 of 3 years for navel orange fruit (Boman, 1992).

The effects of irrigation on fruit TSS:TA ratios are variable. Sites et al. (1951) found a significantly higher fruit TSS:TA ratio for irrigated 'Duncan' grapefruit trees compared to nonirrigated trees, but no difference in fruit TSS:TA ratio for 'Marsh' grapefruit trees. Many other irrigation studies have reported no difference in fruit TSS:TA ratios (Bielorai, 1982; Graser and Allen, 1987; Hilgeman and Sharpe, 1970; Koo and Smajstrla, 1984; Metochis, 1989). For example, Boman (1992) found similar fruit TSS:TA ratios for trees irrigated at 30% and 50% soil water depletion. However, in the Conserv II project fruit

TSS:TA ratio was increased in 4 of 6 years for trees receiving reclaimed wastewater compared to well water trees. (Zekri and Koo, 1993).

Young citrus tree irrigation

Irrigation of young citrus trees is substantially different from that of mature citrus trees. Young citrus trees because of their limited root zone are more susceptible to water stress than mature citrus trees and require more frequent irrigations. In Florida 68% of growers use microsprinklers to irrigate young citrus trees (Taylor et al., 1989). Smajstrla (1993) reported that microirrigation increased young tree growth compared with conventional irrigation methods and the return on investment is often realized 1- to 2-years earlier using microirrigation.

In Arizona, trickle and basin irrigation systems provided the greatest growth and reduced water use for young orange trees compared to flooding and sprinkler irrigation (Roth et al., 1974). In Texas, Leyden (1975) compared strip, ring and drip irrigation on newly planted grapefruit trees. Tree growth was similar during the first 2 years for all three irrigation methods. Similarly, Swietlik (1992) for 'Ray Ruby' grapefruit found that tree growth was similar for trees trickle or flood irrigated at 16% and 50% soil water depletion, respectively, but flood irrigated trees used 90% less water. In Florida, 'Valencia' orange trees irrigated at 45% soil water depletion were more vigorous than trees irrigated at 30% or 55% soil water depletion on an Arredondo fine sand.

In addition, the soil was continuously wet for trees irrigated at 30% soil water depletion (Smajstrla et al., 1985). Marler and Davies (1990) found that microsprinkler irrigated 'Hamlin' orange trees at 20-45% soil water depletion were more vigorous than trees irrigated at 65% soil water depletion on a Kanapaha fine sand. Maintaining high soil moisture levels required irrigation 2 to 3 times per week during periods of no rainfall.

Flooding

Flatwoods soils are poorly drained due to low elevation and the presence of a relatively impermeable subsurface layer, which often leads to periods of flooding. Frequent irrigations required with reclaimed wastewater use may lead to flooding or increase the level of the water table. Irrigations or rainfall of 3.8 mm have been shown to influence the level of the water table on flatwoods soils (Obreza and Admire, 1985). Flooding results in reduced photosynthesis and growth, dieback and sometimes death of citrus trees in the flatwoods (Ford, 1964; Reitz and Long, 1955; Young, 1943; Young, 1951).

Plant responses to flooding have been reviewed by Kozlowski (1984) and Schaffer et al. (1992). Flooding tolerance is most often defined as the plant's ability to grow and survive in soils when water content is above field capacity (Andersen et al., 1984). However, growth reductions are often not apparent until long after the period of flooding (Kozlowski, 1984). Most plant responses to flooding result from a reduction in oxygen in the root zone

(Bradford and Yang, 1981). Citrus trees are characterized as flood sensitive compared to other fruit crops (Kozlowski, 1984; Schaffer et al., 1992), but flooding tolerance varies among citrus rootstocks. For example, 'Hamlin' orange trees on sour orange rootstock flooded for 30 days resulted in dieback or death of 90% of the trees, whereas trees on rough lemon rootstock after flooding for 60 days, only 20% of trees had dieback or were dead (Vu and Yelenosky, 1991; Vu and Yelenosky, 1992).

Flooding affects several physical, physiological and biochemical processes in the soil and the plant. Flooding restricts pore space and limits oxygen diffusion to the roots (Graser and Allen, 1988; Kramer, 1951; Stolzy and Letey, 1965). Decreases in soil oxygen resulted in decreased root and top growth of apples (Childers and White, 1942), prunes, peaches (Boynton and Compton, 1943), and citrus (Bevington and Castle, 1985; Syvertsen et al., 1983). Roots of citrus seedlings growing in soil with an oxygen diffusion rate (ODR) of less than 0.11 $\mu g \cdot cm^{-2} \cdot min^{-1}$ stopped growing and were damaged. In contrast, citrus roots grew in soil with an ODR of 0.22 to 0.24, but at a reduced rate when compared to soils with an ODR above 0.63 (Stolzy et al., 1965). Shoot growth and root health of citrus seedlings declined within 8 days of flooding due to anoxic soil conditions (Syvertsen et al., 1983). Similarly, shoot growth and root health of field grown citrus trees declined after 14 days of flooding (Graser and Allen, 1988). Low oxygen levels reduced root permeability and restricted water uptake (Graser and Allen, 1987). Schaffer and Moon

(1990) found that 'Tahiti' lime trees exposed to flooding for 7 days had reduced net CO_2 assimilation and transpiration, but net CO_2 and transpiration generally recovered to pre-flooding levels after 7 days of nonflooding. Citrus trees under flooded conditions resulted in decreases in leaf water potential (Ford, 1984; Graser and Allen, 1987; Phung and Knipling, 1976; Syvertsen et al., 1983), stomatal conductance (Ford, 1984; Graser and Allen, 1987; Vu and Yelenosky, 1991), transpiration (Phung and Knipling, 1976; Schaffer and Moon, 1990), and net CO_2 assimilation (Phung and Knipling, 1976; Schaffer and Moon, 1990; Syvertsen et al., 1983; Vu and Yelenosky, 1992).

Nutrient uptake by plants is also affected by flooding. Levels of N, P, K, Ca, Mg, Mn and Zn were reduced in avocado leaves for trees grown in flooded soils with O_2 levels of <2% (Slowik et al., 1979). Concentrations of N, P, K, Ca and Mg decreased while Na increased in citrus seedlings under flooded conditions (Labanauskas et al., 1966). Similarly, B, Cu, Fe, Mn and Zn levels decreased as oxygen decreased, but Na and Cl levels increased in the foliage of citrus seedlings (Labanauskas et al., 1971).

Fertilization

Citrus trees in Florida are generally grown on sandy soils of low native fertility (Koo et al., 1984), therefore fertilization is necessary to attain acceptable growth and production. Reclaimed wastewater has the potential to reduce or eliminate the need to fertilize citrus trees. Applications of macronutrients are

generally required on an annual basis to avoid nutrient deficiencies (Koo et al., 1984), but micronutrients are required less frequently (Koo, 1988; Wutscher and Obreza, 1987).

Fertilization methods

Fertilization methods and timing are changing due to the use of irrigation systems to apply fertilizer ('fertigation'). Nitrogen uptake was affected by method of irrigation with trickle irrigated citrus trees having higher leaf N concentrations than flood-irrigated trees (Roth et al., 1981; Wutscher et al., 1975). Fertilizer efficiency is associated with soil moisture with high soil moisture levels increasing nutrient uptake (Bravdo et al., 1992; Koo, 1979). Koo (1980) found that fertilization of 60% to 70% of the root zone was critical for adequate mature tree growth in Florida. In addition, tree growth was similar for trees receiving fertigation 3- or 10-times/yr or granular fertilizer at comparable rates (Koo, 1980). Likewise, there was no advantage or disadvantage to the combination of granular fertilization and fertigation at 15% and 30% of the total N requirement (Koo and Smajstrla, 1984). However, Dasberg et al. (1988) on mature 'Shamouti' orange trees in Israel observed an increase in yield for trees fertigated at 160 kg N/ha compared to trees receiving broadcast fertilization, but no difference in tree growth or yield between fertilization methods at 280 kg N/ha. Similarly, for young trees Smajstrla (1993) reported that fertigation increased tree growth compared to granular fertilizer. However, Willis et al.

(1991) found no difference in tree growth between fertilization methods (granular vs fertigation) for young 'Hamlin' orange trees. However, fertigation at 30 times/yr increased trunk diameter of 'Hamlin' orange trees on a Carrizo citrange rootstock grown on Arredondo fine sand, but not on a Kanapaha fine sand (Willis et al., 1990).

The loss of nutrients by leaching is a growing concern due to the potential contamination of waterways and ground water. Frequent fertilizer applications ensure that nutrients are being supplied to the tree and reduce losses from excessive rainfall or irrigation (Ferguson and Davies, 1989). Rainfall or irrigation above field capacity are major causes of nutrient leaching (Mansell et al., 1980). Willis et al. (1990) found that for young citrus trees most N leaching occurred when recommended levels (0.22 kg N/tree per yr) of fertilizer were applied 5 times/yr, but N leaching was significantly reduced with more frequent applications. Similarly, for mature citrus trees leaching accounted for < 50 kg N/ha for trees fertilized at 100 and 180 kg N/ha, but leaching resulted in losses of > 50 kg N/ha for tree receiving 280 kg N/ha. Significant quantities of N were unaccounted for and may be incorperated in the soil organic matter (Dasberg et al., 1984).

Mature citrus tree fertilization

Fertilization of mature citrus trees is essential to maintain a highly productive grove. Fertilization rates have been established for many citrus

producing areas (Calvert and Reitz, 1964; Dasberg et al., 1983; Hume et al., 1985; Koo et al., 1984; Reese and Koo, 1976; Reitz and Koo, 1959; Sites et al., 1953; Sites et al., 1961). In Florida, current fertilizer recommendations for mature citrus trees are based on the previous seasons yield. Nitrogen rates are based on 0.14 and 0.18 kg N/box of fruit for grapefruit and orange trees, respectively (Koo et al., 1984). Mature citrus trees require 100 to 340 kg N/ha per yr however rates above 225 kg N/ha are rarely justified.

Numerous field studies have been conducted to determine the optimum number and timing of N fertilization for mature citrus trees. Leyden (1966) in Texas found that fertilizer applied prior to bloom resulted in higher yield than applications after bloom. In contrast, Dasberg et al. (1983) in Israel found that leaf growth of the spring flush was dependent mainly on tree N reserves and not uptake from the soil. In Florida, frequency and timing of fertilization had minimal effects on tree growth compared to fertilization rate (Calvert and Reitz, 1964; Reuther and Smith, 1954; Sites et al., 1961). Tree growth was similar for trees receiving 1- or 2-fertilizations a year, but more frequent applications were unwarranted under normal conditions. However, trees planted on coarse or shallow soils may require 3- or 4-applications a year because of leaching or a restricted root system. Likewise, more frequent applications may be necessary in years of heavy rainfall or following hurricanes (Koo et al., 1984).

Young citrus tree fertilization

Nutrient requirements have been established for young citrus trees grown on the flatwoods (Calvert, 1969) and Ridge areas of Florida (Rasmussen and Smith, 1961). Current fertilizer recommendations range from 0.14-0.27, 0.25-0.41, and 0.35-0.58 kg N/tree per yr applied 5-6, 4-5 and 3-4 times/yr for 1-, 2-, and 3-year old trees, respectively (Ferguson and Davies, 1989; Koo et al., 1984). In addition, it is recommended that fertilization include nutrients in the following ratios 8N-8P-8K-1.6Mg-0.4Mn-0.2Cu-0.05B. Willis et al. (1991) found that trees fertigated at recommended rates (0.22 kg N/tree per yr) produced the most vigorous growth compared to trees receiving 0.06 and 0.11 kg N/tree per yr. However, Marler et al. (1987) found no difference in tree growth for trees receiving 0.07 or 0.22 kg N/tree per yr. Likewise, Guazzelli (1994) found no difference in tree growth related to fertilization rate in the first year. Recent research indicates that fertilization at one-half (0.11 kg N/tree per yr) the recommended rate (0.22 kg N/tree per yr) produced trees of similar vigor (Ferguson et al., 1990; Obreza, 1990; Obreza and Rouse, 1993). In addition, newly planted citrus trees may have considerable N reserves from the nursery, which may account for similar tree growth in the first year.

Reset Citrus Trees

Literature on reset citrus trees is limited and most information on reset management comes from young tree studies. Resets are defined as trees 1- to

3-years old planted to replace dead or unproductive trees within an established grove (Florida Dept. of Agr., 1992). Reset management is essential in maintaining a highly productive and economically viable grove with over 50% of growers planting resets annually (Ferguson and Taylor, 1993).

Tree losses in Florida are associated with climatic conditions and the increased incidence of disease. Annual losses of mature citrus trees typically average 4% to 5% a year (Ferguson and Taylor, 1993; Muraro, 1988; Muraro and Holcomb, 1993) and losses of 4% to 6% of resets in the first year after planting (Jackson et al., 1986; Taylor et al., 1989). Tree losses are often accelerated by diseases such as foot rot and blight or the occurrence of severe freezes.

The care and management costs of resets are significantly higher than for solid plantings of young citrus trees (Jackson et al., 1986; Muraro and Niles, 1976) because resets are typically scattered throughout an established grove. Fertilization and irrigation of resets is likewise difficult as resets must compete with mature citrus trees and weeds for available soil nutrients and moisture. Reset fertilization is important to prevent nutritional deficiencies and stimulate growth (Jackson, 1981). In addition, weed control is particularly important as weeds compete for available soil moisture and nutrients and can significantly reduce young tree growth (Smajstrla et al., 1985). Resets having a limited root zone often do not receive adequate water when irrigated on a mature tree schedule or irrigation system (Jackson, 1981). Currently, about

70% of reset acreage is irrigated with microsprinklers with 57% of the irrigation systems designed for fertigation (Ferguson and Taylor, 1993). However, fertigation or granular materials applied at mature grove rates may be inadequate to meet the nutritional requirements of resets because of their limited root zone, thus supplemental fertilization may be necessary. The use of controlled release fertilizers may be particularly useful for fertilization of resets to reduce application frequency and reduce leaching of the fertilizer (Obreza, 1990).

Reclaimed wastewater

Reclaimed wastewater has been successfully used to irrigate many agronomic crops, such as sorghum (Day and Cluff, 1985), cotton (Bielorai et al., 1984; Feigin et al., 1984; Oran and DeMalach, 1987; Papadopoulos and Stylianou, 1988a), bermuda grass (Day et al., 1984; Hayes et al., 1990; Mancino and Pepper, 1992), Kentucky bluegrass, reed canary grass, orchard grass, tall fescue (Clapp et al., 1984; Marten et al., 1979), smooth bromegrass, quackgrass, Timothy (Marten et al., 1979), rye grass (Hayes et al., 1990), corn, alfalfa (Campbell et al., 1983; Marten et al., 1979), sunflower (Papadopoulos and Stylianou, 1991), wheat (Campbell et al., 1983; Tripathi et al., 1990), vegetables (Neilsen et al., 1989c; Schalscha and Vergara, 1982; da Costa Vargas et al., 1991) and forest trees (Hopmans et al., 1990; Stewart and Flinn, 1984; Stewart et al., 1990). Reclaimed wastewater has also been used for

irrigation of fruit crops such as grapes (Neilsen et al., 1989b), cherries (Neilsen et al., 1991), peaches (Basiouny, 1984), apples (Neilsen et al., 1989a), and citrus (Kale and Bal, 1987; Koo and Zekri, 1989; McMahan et al., 1989; Omran et al., 1988; Overman et al., 1987; Parsons and Wheaton, 1992; Wheaton and Parsons, 1993; Wood, 1988; Zekri and Koo, 1990; Zekri and Koo, 1993).

Reclaimed wastewater composition and treatment costs vary considerably with location. Water quality is dependent on three major variables; 1) quality of the original water source; 2) type of use; and 3) renovation treatment (primary, secondary or tertiary treatment of the influent) (Berry et al., 1980). However, reclaimed wastewater composition varies locally and temporally even within the same treatment facility (Basiouny, 1982). Treatment facilities with secondary treatment filtration and disinfection produce reclaimed wastewater which can be used for non-restricted irrigation (Rose and Gerba, 1991) and can become a permanent component in an integrated water supply system (Asano and Tchobanoglous, 1991). The cost of reclaimed wastewater depends on whether the local treatment facility personnel view the reclaimed wastewater as a disposal problem or as the marketing of a natural resource (Berry et al., 1980). In Florida, reclaimed wastewater at the Conserv II project is an inexpensive water source as compared to pumping ground water because water and pumping costs are free to the grower (McMahan et al., 1989).

Treated reclaimed wastewater contains many plant nutrients in varying concentrations (Berry et al., 1980; Bielorai et al., 1984; Feigin et al., 1984). Plant nutrients in reclaimed wastewater are typically considered pollutants, as N and P can cause eutrophication of streams and lakes when disposed of into waterways (Sanderson, 1986). Conversely, the presence of a crop on land used for reclaimed wastewater disposal could remove unwanted materials (Terry and Tate, 1981) and the use of plant nutrients may prevent pollution of surface and ground waters (Sanderson, 1986). In addition, irrigation with reclaimed wastewater may be similar to continuous fertigation with a dilute concentration of plant nutrients, particularly N, P and K (Berry et al., 1980; Neilsen et al., 1989a).

Reclaimed wastewater use has been associated with increases in growth and production of many agronomic crops (Campbell et al., 1983; Day et al., 1984; Hayes et al., 1990; Marten et al., 1979; Neilsen et al., 1989c; Oron and DeMalach, 1987; Papadopoulos and Stylianou, 1988b; Papadopoulos and Stylianou, 1991). Similarly, proper management of reclaimed wastewater irrigation for fruit crops may produce economic gains of 25-30% (Basiouny, 1982). Increases in growth and production from reclaimed wastewater irrigation have been reported for peaches (Basiouny, 1984), apples (Neilsen et al., 1989a), cherries (Neilsen et al., 1991), grapes (Neilsen et al., 1989b) and citrus in India (Kale and Bal, 1989), Egypt (Omran et al., 1988), and Florida (Koo and

Zekri, 1989; Parsons and Wheaton, 1992; Wheaton and Parsons, 1993; Zekri and Koo, 1993).

Reclaimed wastewater has the potential to add considerable quantities of plant nutrients to the crop. In Chile, untreated reclaimed wastewater added an estimated 780 kg N/ha per yr to vegetable crops via irrigation with 160-290 kg N/ha removed by the crop (Schalscha and Vergara, 1982). However, current regulations in Florida require that reclaimed wastewater released from the treatment facility contain $\leq$ 10 mg·liter^{-1} NO_3^- (Florida Dept. of Environmental Regulation, 1982). The volume of reclaimed wastewater used and concentration of elements within the reclaimed wastewater determine the amount of each element applied. Reclaimed wastewater limited the amount of N and P fertilizer necessary to obtain high yields for sunflowers (Papadopoulos and Stylianou, 1991) and vegetables (Neilsen et al., 1989c). Turfgrass irrigated with reclaimed wastewater showed signs of over-fertilization when N levels were not reduced (Hayes et al., 1990). Nitrogen concentrations increased in cotton plants receiving reclaimed wastewater compared to plants receiving well water (Papadopoulos and Stylianou, 1988a). Likewise, N from reclaimed wastewater was efficiently taken up by sudax (*Sorghun vulgare* x *S. sudanense*)(Papadopoulos and Stylianou, 1988b). In Australia, Stewart et al. (1990) estimated that river red gum, flooded gum, Sydney blue gum, river she-oak, radiata pine and poplar trees accumulated about one-third of the N applied in reclaimed wastewater. Leaf N, P and K concentrations were

increased in fruit crops receiving reclaimed wastewater for cherries (Neilsen et al., 1991), grapes (Neilsen et al., 1989c), apples (Neilsen et al., 1989a), and peaches (Basiouny, 1984). For citrus Omran et al. (1988) found increases in leaf N content for trees receiving reclaimed wastewater, but Zekri and Koo (1993) found no difference in leaf N concentration due to high rates of N fertilization for trees receiving reclaimed wastewater and well water. Similarly, leaf K levels were the same for all treatments possibly due to yield. However, leaf P was significantly increased for trees receiving reclaimed wastewater compared to well water trees (Zekri and Koo, 1993).

Fruit growth and quality characteristics are also influenced by reclaimed wastewater. Fruit from peach trees irrigated with reclaimed wastewater reached maturity 7 to 10 days earlier than trees receiving well water. Titratable acidity (TA) levels were reduced, but total soluble solids (TSS) increased (Basiouny, 1984). In contrast, fruit TA was not affected, but pH and TSS were increased for grapes irrigated with reclaimed wastewater (Neilsen et al., 1989b). Reclaimed wastewater irrigation of 'McIntosh' and 'Red Delicious' apple trees increased fruit number compared to trees receiving well water, but fruit size was increased only for 'Red Delicious' apples (Neilsen et al., 1989a). In Egypt, Omran et al. (1988) found increases in fruit weight, peel thickness and yield for 'Valencia' orange trees irrigated with reclaimed wastewater, but juice quality was not affected compared to well water irrigated trees. In Florida, reclaimed wastewater increased fruit size, juice content and TSS:TA ratio, but decreased

TSS and TA as compared to trees receiving well water for 'Valencia' and 'Hamlin' oranges and 'Orlando' tangelos (Zekri and Koo, 1993).

Heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni and Zn) are potential hazards associated with reclaimed wastewater irrigation (Aboulroos et al., 1991; Basiouny, 1982; Campbell et al., 1983; El Nennah et al., 1982; Omran et al., 1988; Waly et al., 1987). Toxic levels of heavy metals may limit plant growth and present a health risk to humans. However, Cd, Cu, Ni and Zn at low levels are essential elements for humans (Kirkham, 1986). Heavy metal content varies depending on the source of water. Non-industrial wastewater typically has lower levels of heavy metals than industrial wastewater. Soluble heavy metals in the soil solution typically increase with duration of reclaimed wastewater use and may with time reach phytotoxic levels (El Nennah et al., 1982). Aboulroos et al. (1991) found that heavy metals were primarily in nonexchangeable forms and therefore not available for plant uptake. However, non-exchangeable and exchangeable heavy metals are in equilibrium in the soil and non-exchangeable heavy metals may become available for plant uptake. In Utah, where reclaimed wastewater was applied to agricultural land for 20 years, soil heavy metal concentrations were not significantly increased from the control as reclaimed wastewater and well water had similar heavy metal concentrations (Campbell et al., 1983). In Egypt, concentrations of heavy metals in the soil after irrigation with reclaimed wastewater for up to 70 years were within permissible limits for plant growth (Waly et al., 1987). Citrus trees grown on

these soils had the highest levels of heavy metals in the leaves followed by the peel and juice (Omran et al., 1988), but were below levels causing any toxic affects in plants or humans. In Florida, at the Conserv II project heavy metals have not been a concern due to pretreatment of industrial wastewater and trace or non-detectable levels in the reclaimed wastewater (McMahan et al., 1989).

Elements such as Na, Cl and B in reclaimed wastewater may limit plant growth if allowed to accumulate to phytotoxic concentrations. However, in areas of high rainfall and soils with low cation exchange capacity allow for the use of irrigation water with higher salinity levels than is generally considered safe (Basiouny, 1984). Salinity is generally of concern only in arid regions in which accumulated salts are not flushed from the soil by precipitation (Kirkham, 1986). In Florida, where rainfall is plentiful soluble salts from reclaimed wastewater may not accumulate to levels which limit plant growth. Increases in Na and Cl concentrations from reclaimed wastewater irrigation have been reported for many agronomic crops (Mancino and Pepper, 1992; Stewart et al., 1990; Tripathi et al., 1990; Waly et al., 1987). However, in some locations reclaimed wastewater may have a lower salinity level than alternative water sources and thus provide a higher quality of irrigation water (Kale and Bal, 1987). Reclaimed wastewater applied through overhead irrigation systems may cause foliar injury; therefore under tree irrigation systems are recommended (Basiouny, 1982). Reclaimed wastewater typically contains B

levels ranging from 0.5 to 1.0 mg·liter^{-1} (Kirkham, 1986). Boron is used in household cleaners and detergents (Basiouny, 1982). Increases in leaf B from reclaimed wastewater use have been reported for peaches (Basiouny, 1984), cherries (Neilsen et al., 1991), and citrus (Zekri and Koo, 1993). In Egypt, prolonged reclaimed wastewater irrigation resulted in a slight increase in soil Na levels, but soil Cl levels remained unchanged (Waly et al., 1987). In the Conserv II project leaf Na and Cl levels increased for trees receiving reclaimed wastewater compared to well water treated trees (Zekri and Koo (1993). However, in all these experiments with reclaimed wastewater no adverse effects on plant growth from B, Cl or Na were reported.

A major concern in the use of reclaimed wastewater is the possible presence of pathogenic microorganisms and potential health risk to workers and consumers. Untreated sewage contains many pathogenic microorganisms including over 120 enteric viruses (Rose and Gerba, 1991). After secondary treatment filtration and disinfection there is no evidence of increased risk to workers or consumers from reclaimed wastewater irrigation (Basiouny, 1982; Berry et al., 1980; Brenner et al., 1988; Rose and Gerba, 1991); however, conventional systems cannot guarantee completely pathogen-free reclaimed wastewater (Gleason et al., 1984). In Portugal, lettuce which was sprinkler-irrigated with low quality reclaimed wastewater met standards for viruses and pathogens within 5 days after ceasing irrigation (da Costa Vargas et al., 1991). Likewise, citrus fruit dipped directly into untreated reclaimed wastewater had

no enteric viruses in the fruit or on the peel following washing with standard packinghouse procedures (A. Lewis, Florida State Dept. of Health and Rehabilitative Services, personnel communication). Pathogenic contamination of fruit trees by treated reclaimed wastewater is very unlikely because pathogenic organisms are not present in the effluent. (Basiouny, 1982). In Florida, reclaimed wastewater from the Conserv II project had no detectable enteric viruses after treatment. In addition, regulations prohibit overhead sprinklers for reclaimed wastewater irrigation to prevent direct contact of fruit with the reclaimed wastewater (McMahan et al., 1989).

Freeze Hardiness

Freeze hardiness of citrus trees has been associated with various plant nutrients. Trees receiving high rates of phosphate were more severely injured by freezing temperatures than trees receiving low rates of phosphorus (Spencer, 1958; Spencer, 1960). However, Smith and Rasmussen (1958), found no effect of leaf P concentration on freeze damage of citrus, while Zekri and Koo (1990) observed that leaves with higher P levels had less freeze damage. High levels of K have also been reported to decrease freeze hardiness of citrus trees (Koo, 1985a; Smith and Rasmussen, 1958). In contrast, Jackson and Gerber (1963) found no relationship between leaf K concentration and freeze hardiness. Low or deficient Mg levels increased freeze damage (Lawless, 1941), and Zekri and Koo (1990) observed that trees

with high leaf Mg levels survived better than trees at lower leaf Mg levels. In Texas, Swietlik and LaDuke (1985) observed that low Mn levels were associated with groves receiving extensive freeze damage. Lawless (1941) observed that Zn and Cu deficiencies greatly decreased freeze hardiness. However, Smith and Rasmussen (1958), observed no differences in trees freeze hardiness related to Cu, Mn or Zn levels.

Leaf N levels have long been associated with freeze hardiness of citrus trees. Sharples and Burkhart (1953) observed low N leaves (1.7%) were less freeze tolerant than leaves with 2.0% N. Smith and Rasmussen (1958) observed that ammonium sulfate increased freeze damage compared to calcium nitrate and ammonium nitrate, but that there was a clear tendency for high N rates (1.6-1.8 kg N/tree per yr) to reduce freeze damage. Similarly, in Korea Cheong and Moon (1989) found that among the various leaf nutrients tested, N was the only element that showed a correlation with leaf freezing tolerance. Nitrogen fertilization up to twice the standard level increased freeze hardiness, whereas three times the standard level did not further increase freeze hardiness. Conversely, Koo (1981) observed no difference in freeze damage related to leaf N in the freeze of 1977, but in the 1981 freeze branch dieback was greatest in high N (290 kg N/ha per yr) vs. low N plots (112 kg N/ha per yr). Smith and Rasmussen (1958) found less freeze damage on 'Marsh' grapefruit trees with leaf N levels of 2.86% compared to 2.64% and a similar trend for 'Valencia' oranges. Likewise, Koo (1985a) observed increased

freeze damage when leaf N content was below 2.5% than when leaf N content was 2.5-2.8%.

Fertilization practices have a relatively small affect on freeze hardiness of citrus when obvious deficiencies are absent (Lawless and Camp, 1940; Smith and Rasmussen, 1958). However, tree size and foliage density appear to be important parts of citrus tree freeze hardiness as healthy trees reduced radiation losses (Lawless, 1941; Smith and Rasmussen, 1958; Spencer, 1960), but smaller less vigorous trees may have had nutrient deficiencies (Lawless and Camp, 1940). Increased tree vigor and canopy size may function to prevent radiation losses as temperatures within the tree canopy can vary up to 2 C (Davies et al., 1981). For young nonbearing citrus trees high N levels increased freeze hardiness (Smith and Rasmussen, 1958), however, late applications of N that may promote active growth or delay nonapparent growth reduced freeze hardiness of young citrus trees (Smith and Rasmussen, 1958). In contrast, Maxwell and Shull (1963) found no effect of fertilization timing on tree freeze hardiness.

Freeze hardiness of citrus trees is related to many other factors such as leaf water content (Davies et al., 1981; Husain and Cooper, 1958; Koo, 1981; Yelenosky and Guy, 1989), leaf solute levels (Purvis and Yelenosky, 1983; Sharples and Burkhart, 1953; Yelenosky, 1978; Yelenosky, 1982; Young and Peynado, 1965), soil temperature (Wilcox et al., 1983), air temperature (Hutcheson and Wiltbank, 1970; Rouse and Wiltbank, 1972; Yelenosky and

Young, 1977), rootstock (Rouse et al., 1990; Wutscher, 1979; Yelenosky and Wutscher, 1985; Yelenosky et al., 1981) and level of dormancy (Cooper, 1959; Young, 1961; Young and Peynado, 1962; Young et al., 1960). Acclimation of citrus trees is dependent on both soil and air temperature (Hutcheson and Wiltbank, 1970; Rouse and Wiltbank, 1972; Wilcox et al., 1983; Yelenosky and Young, 1977). Yelenosky and Young (1977) found that freeze hardiness began to increase 2 weeks after night temperature below 10 C in a growth chamber. However, citrus trees began to deacclimate within 1 week of 24/18 C day/night temperatures (Young and Peynado, 1965). In Florida, fluctuating temperatures may cause trees to acclimate and deacclimate multiple times during the winter (Wiltbank and Oswalt, 1983).

Freeze hardiness of citrus trees has been determined by many methods. Freeze chambers in the field (Cooper, 1959; Young et al., 1960) or growth chambers (Young and Peynado, 1962) have been used to determine citrus tree freeze hardiness based on tree damage and regrowth. Freeze hardiness has also been determined by the leaf freezing point method of attached and detached citrus leaves (Gerber and Hashemi, 1965; Jackson and Gerber, 1963). Jackson and Gerber (1963) found the leaf freezing point was similar for attached and detached citrus leaves. Likewise, leaf freeze hardiness was similar regardless of location of the leaf on the tree (Gerber and Hashemi, 1965; Hutcheson and Wiltbank, 1970). More recently leaf killing points using the electrolyte leakage method have been used to determine freeze hardiness

of citrus (Anderson et al., 1983; Wiltbank and Oswalt, 1983). The electrolyte leakage method resulted in similar leaf freeze hardiness levels as previous methods and was similar to freeze hardiness from regrowth test.

The focus of this literature review has been on the potential advantages and disadvantages of using reclaimed wastewater for irrigation. Reclaimed wastewater may be a source of water and plant nutrients which are essential for plant growth. However, potential hazards such as heavy metals, salinity, bacteria and viruses from reclaimed wastewater have also been discussed. Understanding how these factors may influence mature, reset and young citrus tree growth, development and production are important to the scope of this research.

CHAPTER III

RECLAIMED WASTEWATER IRRIGATION AND FERTILIZATION OF MATURE 'REDBLUSH' GRAPEFRUIT TREES ON FLATWOODS SOILS

Introduction

In Florida, 34% of agriculturally available water is used to irrigate citrus trees (Smajstrla et al., 1992). Competition for limited water resources is increasing between urban, industrial and agricultural interests. This competition is especially acute in the coastal areas of Florida where salt water intrusion is often a problem due to excessive demand on the ground water supply. In addition, urban growth in the coastal areas of Florida has increased the need for efficient and environmentally safe disposal of municipal reclaimed wastewater. Currently, about one-half of all citrus is grown in flatwoods areas of Florida (Florida Dept. of Agr., 1992). The use of reclaimed wastewater for irrigation of citrus is potentially beneficial to both urban and agricultural interests. Reclaimed wastewater could provide an economical means of irrigating, decrease pollution of surface waters and provide ground water recharge.

Reclaimed wastewater has been used to irrigate apples (Nielsen et al., 1989a), cherries (Nielsen et al., 1991), grapes (Nielsen et al., 1989b), peaches (Basiouny, 1984) and citrus (Kale and Bal, 1987; Koo and Zekri, 1989; Omran et al., 1988; Wheaton and Parsons, 1993; Zekri and Koo, 1990; Zekri and Koo, 1993). The use of reclaimed wastewater for irrigation of citrus trees has several potential advantages. Reclaimed wastewater contains many essential nutrients for plant growth and its application may reduce fertilizer application rates (Neilsen et al., 1989a). The uptake of plant nutrients in reclaimed wastewater and reduction in fertilizer use may prevent surface and/or ground water contamination (Sanderson, 1986). In addition, reclaimed wastewater may be used for freeze protection (McMahan et al., 1989). Potential disadvantages of using reclaimed wastewater include accumulation of phytotoxic levels of heavy metals (Omran et al., 1988), salinity (Basiouny, 1982; Kirkham, 1986) and concern over the health risk associated with viruses and bacteria in the water (Basiouny, 1982; Berry et al., 1980; Brenner et al., 1988; Gleason et al., 1984; Rose and Gerba, 1991).

Reclaimed wastewater has been used for irrigation of citrus on the deep sandy soils of the Ridge area of Florida (Wheaton and Parsons, 1993; Zekri and Koo, 1993), but no in depth studies have been conducted on the east coast flatwoods where soil type and drainage patterns vary considerably due to the presence of hard pans and a high water table. The objective of this experiment was to evaluate the effects of various irrigation rates with reclaimed

wastewater on the growth and development, fruit quality and yield of mature 'Redblush' grapefruit trees on flatwoods type soils. In addition, the effects of reclaimed wastewater on soil moisture levels throughout the year were also studied. The overall goal of this study was to determine whether citrus growers can safely and economically use reclaimed wastewater for citrus irrigation on flatwoods-type soils.

Materials and Methods

The experimental site consisted of an 8.1 ha block of 25-year old 'Redblush' grapefruit trees (*Citrus paradisi* Macf.) on sour orange (*C. aurantium* L.) rootstock. The study was conducted from 1 Oct. 1990 to 16 Apr. 1994. The site was located adjacent to the Indian River County municipal wastewater treatment facility located near Vero Beach, Fla. Trees were planted on double beds 18.3 m wide and 177 m in length. The crest of the bed was ca. 1 m above the bottom of the water furrows. Trees were spaced 9.15 m between and 6.1 m within rows (29 trees/row). The soil type was predominantly a Wabasso fine sand (sandy, siliceous, hyperthermic Alfic Haplaquods) with areas of Chobee loamy fine sand (fine-loamy, siliceous, hyperthermic Typic Argiaquolls) and EauGallie fine sand (sandy, siliceous, hyperthermic Alfic Haplaquods) occurring in portions of the block. The soil had a volumetric field capacity of 9.95%, a permanent wilting point of 2.48% and a mean bulk density of 1.61 $g \cdot cm^{-3}$.

Four treatments were arranged in a completely randomized design with each double bed representing a replicate (four replicates/treatment). Irrigation treatments were arranged in this manner to assure statistical validity and because it was impractical to irrigate an area smaller than an entire bed. Treatments consisted of a control (canal water) irrigated based on soil water depletion of one-third from Jan.-June. and two-thirds from July-Dec. (Koo, 1963) and reclaimed wastewater (secondary treated municipal wastewater) applied at low (23.1), moderate (30.7) and high (38.6 $mm \cdot wk^{-1}$) rates (Tables 3.1-3). Trees were irrigated using 56.8 liter/h, 360° Maxijet® microsprinklers (two/tree) located within the tree row. The wetting pattern was 4.3 m in diameter at 101 kPa pressure. The arrangement of the microsprinklers overlapped sufficiently to provide coverage of the entire grove floor within the tree rows. The drive and furrow rows between tree rows were not irrigated. Trees receiving the low and moderate-reclaimed wastewater treatments were irrigated 2 days/wk and the high-reclaimed wastewater treatment 3 days/wk. Reclaimed wastewater for all treatments combined were applied 4- or 5-days/wk during each year, with the exception of times when the water furrows were being cleaned in December 1991 (Table 3.4).

All treatments received about 135 kg N/ha per yr. The control treatment was fertilized two times/yr (½ on 15 Feb, 1990, ½ on 15 Aug, 1990) using a 12N-2P-16K analysis granular fertilizer. Since reclaimed wastewater contains N, P, K and other nutrients, fertilizer rates were adjusted for these treatments to

Table 3.1. Total water applied via irrigation to 'Redblush' grapefruit trees at Vero Beach, Fla., 1990-91.[z]

Treatments	Oct.-Dec.	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.[y]	Total
	(kl)					
Control						
Canal water	273	305	519	0	1651	2749
Reclaimed wastewater						
Low - 23.1 mm·wk^{-1}	1988	2138	1901	1849	1600	9477
Mod. - 30.7 mm·wk^{-1}	2295	2712	2344	2499	2136	11986
High - 38.6 mm·wk^{-1}	3015	3354	2999	2825	2653	14846

[z] Water was applied to a 0.086 ha area within each tree row.
[y] Irrigation was discontinued from 25 Nov. to 16 Dec. 1991 to clean and repair the water furrows.

Table 3.2. Total water applied via irrigation to 'Redblush' grapefruit trees at Vero Beach, Fla., 1992.[z]

Treatments	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(kl)		
Control					
Canal water	727	1974	0	0	2700
Reclaimed wastewater					
Low - 23.1 mm·wk^{-1}	870	2085	2045	1650	7650
Mod. - 30.7 mm·wk^{-1}	2386	2771	3195	2235	10587
High - 38.6 mm·wk^{-1}	2986	2979	3935	2981	12881

[z] Water was applied to a 0.086 ha area within each tree row.

Table 3.3. Total water applied via irrigation to 'Redblush' grapefruit trees at Vero Beach, Fla., 1993.[z]

Treatments	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(kl)		
Control					
Canal water	87	978	1002	110	2176
Reclaimed wastewater					
Low - 23.1 mm·wk^{-1}	1755	2182	1960	1570	7468
Mod. - 30.7 mm·wk^{-1}	2354	2870	2661	2098	9982
High - 38.6 mm·wk^{-1}	2821	3561	3318	2616	12315

[z] Water was applied to a 0.086 ha area within each tree row.

Table 3.4. Four and five day schedules and amounts of reclaimed wastewater irrigation for 'Redblush' grapefruit trees, Vero Beach, Fla., 1990-93.[z]

Five day irrigation schedule.					
Treatments	Mon.	Tue.	Wed.	Thur.	Fri.
			(mm/day)		
Low - 23.1 mm·wk^{-1}	7.7			15.4	
Mod. - 30.7 mm·wk^{-1}		15.4			15.4
High - 38.6 mm·wk^{-1}	15.4		15.4		7.7
Four day irrigation schedule.					
Treatments	Mon.	Tue.	Wed.	Thur.	Fri.
			(mm/day)		
Low - 23.1 mm·wk^{-1}			23.1		
Mod. - 30.7 mm·wk^{-1}		23.1		7.7	
High - 38.6 mm·wk^{-1}	23.1			15.4	

[z] Amount of reclaimed wastewater applied to 'Redblush' grapefruit trees.

standardize nutrient levels among treatments. In 1991, granular fertilizer (10N-2P-15K) was applied on 15 Mar. at 67, 51, 28 and 0 kg N/ha for the canal water, low, moderate and high-reclaimed wastewater treatments, respectively. The second application was not made in 1991 due to excessive rainfall which prevented fertilizer spreaders from entering the grove. In 1992, granular fertilizer (12N-0P-0K) was broadcast in the tree row on 11 Mar. at 67, 67, 45 and 23 kg N/ha for the canal water, low, moderate and high-reclaimed wastewater treatments, respectively. A second application of granular fertilizer (10N-0P-15K) was made on 7 July and consisted of 67 kg N/ha applied to the canal water treatment. The remaining 70, 95 and 112 kg N/ha was provided in the reclaimed wastewater for the low, moderate and high-reclaimed wastewater treatments, respectively. In 1993, granular fertilizer (12N-0P-15K) was applied on 18 Feb. at 67, 51, 28 and 0 kg N/ha for the canal water, low, moderate and high-reclaimed wastewater treatments, respectively. The second application of granular fertilizer (12N-2P-12K) was made on 30 Aug. at 67 kg N/ha to the canal water treatment. The high-reclaimed wastewater treatment received low levels or no granular fertilizer and received from 107 to 129 kg N/ha per yr from the reclaimed wastewater alone depending on the season.

Soil moisture was monitored with a Troxler 4300 neutron probe (Troxler, Raleigh, N.C.) once a week for the reclaimed wastewater treatments and twice a week for the control treatment. One aluminum access tube was placed at the drip-line about half-way down in the tree row of each bed in 1990-92. In 1993,

additional tubes were placed at the east and west ends of the control beds because of variations in soil moisture content along the bed. Soil moisture content in the control treatment was then determined by taking the average of the three lowest readings from the 12 tubes. These tubes were selected so that trees would be irrigated based on the driest soil conditions to ensure that the control trees would not be under water stress. Neutron probe readings were taken at a depth of 23 cm from the crest of the bed because most of the roots were located in this region and the water table fluctuated between a 30-40 cm depth.

Growth and development

Tree vigor was rated visually prior to imposing irrigation treatments in 1989 and each subsequent year. The grove had been irrigated using flooding, but was converted to microsprinkler irrigation in the fall of 1989. Visual evaluations were made on 17 Nov. 1989, 13 Dec. 1990, 11 May 1991, 14 Sept. 1992 and 23 Dec. 1993. Twelve trees/bed were randomly selected as subsamples for further data collection. Trees were rated from 1 (poorly growing, unhealthy) to 8 (vigorous, healthy) tree. In addition, trunk diameter measurements were taken about 30 cm above ground level each year from 1990-93.

Fruit growth was determined by randomly selecting and tagging eight fruit/tree (two fruit from each quadrant) from four trees/bed and measuring the

fruit equatorial diameter each month. Measurements began on 13 Mar. 1990, 18 Apr. 1991, 14 May 1992 and 11 June 1993 after the initial fruit drop period. Dates varied seasonally due to differences in bloom date. Full bloom occurred in early-Feb. 1990, early-Mar. 1991, mid-Mar. 1992 and mid-April 1993. Fruit growth was measured monthly until harvest, which also varied seasonally.

Leaf tissue analysis

Leaves for mineral nutrient tissue analysis were collected in Aug. 1990 and 91 and Sept. 1992 and 93. In 1990 and 91, 100 mature spring flush leaves from non-fruiting branches were selected from the 12 sample trees in each bed and four beds/treatment. In 1992 and 93, five leaves from four sample trees were collected with three samples/bed and four beds/treatment. This sampling technique permitted us to determine the amount of tree-to-tree variation within a bed. Leaves were then washed in detergent (Dreft; Proctor and Gamble, Cincinnati), rinsed once with running tap water and four times in deionized water, dried at 70C for 48 h and then ground to pass through a ≈ 0.5 mm (40 mesh) screen. Total Kjeldahl N was determined by the micro Kjeldahl procedure (Wolf, 1982) using a rapid flow analyzer (Alpkem Corp., Clackamas, Ore). Leaf P, K, Ca, Mg, Na, B, Cu, Fe, Mn and Zn were determined by ashing a 0.5 g sample in a muffle furnace at 550C for 8 h using Quartz crucibles. The ash was then brought to a volume of 50 ml with 1N HCl and filtered. Samples were than analyzed by the Analytical Research Laboratory, Univ. of Florida,

Gainesville on an Inductively Coupled Argon Plasma Spectrometer (Thermo Jarrell Ash Corp., Boston, MA).

Fruit quality

Fruit weight, juice weight, peel thickness, total soluble solids (TSS), titratable acidity (TA) and TSS:TA ratio were measured monthly beginning in Aug., Sept. and Oct. in 1991, 92 and 93, respectively. This starting date varied yearly based on date of full bloom. Fruit samples consisted of 10 fruit/tree (Wardowski et al., 1979) from three trees/bed and four beds/treatment. Fruit were sectioned equatorially so that peel thickness could be measured with a hand caliper and the juice extracted by hand with a Sunkist motor driven extractor. TSS was determined with a temperature compensating refractometer and TA by titration of a 25 ml aliquot of juice using 0.3125N NaOH to an end-point with phenolphthalein as an indicator (Wardowski et al., 1979).

Levels of Cd, Pb and Ni were determined by taking 7 mm core samples from the peel of 10 fruit/tree from three trees/bed and four beds/treatment on 15 Oct. 1991 and 6 Jan. 1993. The samples were then dried at 70C for 48 h and then processed as previously described for leaf tissue.

Yield

Yield was determined from 1991-94 by counting the number of bins harvested/bed and dividing the total by the number of healthy productive

trees/bed. Yield was then averaged for four beds (replicates)/treatment. In Mar. 1993, a severe storm caused a large number of fruit to drop prior to harvest of some of the trees. An estimate of fruit drop, was made by counting fruit under sample trees in each bed. Fruit drop averaged 20-25% of total yield. In addition, each bed was evaluated yearly for missing or severely diseased trees. The healthy tree count per bed was then revised prior to harvest.

Water quality analysis

Water quality was monitored monthly for both the canal water and reclaimed wastewater by collecting samples at the water input source to the irrigation system (Table 3.5). Three water samples from each source were collected and analyzed for pH, electrical conductivity (EC), NH_4^+, NO_3^-, PO_4^-, K, Ca, Mg, Zn, Cu, Cd, Ni, Pb, Na and B. The pH was determined using a pH meter (Orion Research Inc. model 520A Boston, MA) and EC with a conductance meter (YSI model 35 YellowSprings, OH). Nitrate-N was determined on the rapid flow analyzer (Alpkem Corp. Clackamas, Ore.). Ammonium-N and PO_4^- were determined on an AutoAnalyzer II (Technicon Instruments Corp. Tarrytown, N.Y.). All other nutrients were analyzed by the Analytical Research Laboratory, Univ. of Florida, Gainesville on an Inductively Coupled Argon Plasma Spectrometer (Thermo Jarrell Ash Corp., Boston, MA).

Analysis of influent and effluent water for enteroviruses was made quarterly (Table 3.6). Samples consisted of three 1-liter influent samples

Table 3.5. Average chemical analysis of reclaimed wastewater and canal water from Vero Beach, Fla.[z]

Characteristics	Reclaimed wastewater	Canal water
	Mean ± SD	
pH	7.07 ± 0.10	7.46 ± 0.16
Electrical conductivity	764.6 ± 72.4	1058.0 ± 211.1
Elements	($mg \cdot liter^{-1}$)	
Ammonium nitrogen	0.32 ± 0.41	0.17 ± 0.16
Boron	0.42 ± 0.04	0.11 ± 0.01
Cadmium	ND	ND
Calcium	44.08 ± 23.88	103.24 ± 23.49
Copper	0.003 ± 0.007	0.009 ± 0.011
Lead	0.001 ± 0.005	0.002 ± 0.006
Magnesium	13.64 ± 3.64	27.63 ± 6.28
Nickel	ND	ND
Nitrate nitrogen	5.61 ± 2.20	0.48 ± 0.52
Phosphorus	3.88 ± 1.24	0.13 ± 0.08
Potassium	16.68 ± 2.31	8.32± 2.78
Sodium	136.47 ± 13.68	129.27 ± 25.30
Zinc	0.048 ± 0.021	0.031 ± 0.021

[z] Values represent the mean of three samples/month collected from Oct. 1992 to Nov. 1993.
[ND] None detected or below detectable limits.

Table 3.6. Influent and effluent analyses of enterovirus levels, Vero Beach, Fla. 1990-93.[z]

Sample date	Influent	Effluent
	PFU/liter[y]	
Nov. 19, 1990[x]	79.2	< 0.003
Feb. 12, 1991[x]	1.6	< 0.003
Apr. 29, 1991[x]	0.7	< 0.003
Sept. 11, 1991	380.0	< 0.003
Dec. 9, 1991	28.7	< 0.003
Mar. 17, 1992	21.3	< 0.003
June 11, 1992	166.7	< 0.003
Sept. 1, 1992	466.7	< 0.003
Jan. 11, 1993	188.3	< 0.003
Mar. 25, 1993	62.5	< 0.003
June 10, 1993	325.0	< 0.003
Sept. 23, 1993	625.0	< 0.003
Mean	195.5 ± 290	< 0.003

[z] Numbers represent the mean of three one liter samples taken from the influent and three 387 liter samples from the effluent.
[y] PFU/liter = plaque-forming units per liter.
[x] Analysis was conducted by the Florida Dept. of Health and Rehabilitative Services. All other analyses were done be Dr. S. Farrah, Dept. of Microbiology and Cell Science, Univ. of Fla.

collected at the inlet valve where the wastewater entered the treatment facility and three 387-liter effluent samples collected at the efflux valve. Analysis during 1990-91 was conducted by the State of Florida, Dept. of Health and Rehabilitative Services (HRS). Subsequent analysis was performed by Dr. S. Farrah at the Dept. of Microbiology and Cell Sciences, Univ. of Florida, Gainesville. Procedures used for analysis of enteroviruses levels were modified from those described in the USEPA Manual of Methods for Virology. (Cincinnati, OH).

In addition, eight fruit from both the high-reclaimed wastewater and control treatments were harvested in 17 Mar. 1992 and 18 Feb. 1993 and analyzed for the presence of enteroviruses (Farrah, unpublished). One grapefruit was placed in a sterile beaker with 200 ml of 0.05% beef extract at pH 9. After mixing for 5 min, the solution was removed and concentrated by adjustment to pH 3.5 and addition of 0.005M ferric chloride to enhance flocculation. Samples were centrifuged at 14,500 x g for 10 min. The floc was suspended in 10 ml of 0.15M sodium phosphate and again centrifuged. The supernatant was adjusted to pH 7 and assayed as described in the USEPA Manual of Methods for Virology. (Cincinnati, OH). Seeded studies with poliovirus added to the surface of the grapefruit showed that 58% of the added virus could be recovered in the final sample. Therefore, these techniques gave an accurate representation of the presence of enteroviruses on grapefruit.

Weed intensity

Weed intensity within the tree rows was determined monthly by visual evaluation beginning in Jan. 1992. Ratings ranged from 0 (no weed growth) to 5 (≥ 50% of ground surface covered with weeds). All beds had bahiagrass ground cover between rows which was mowed as necessary. Pest, weed and disease control treatments were applied as currently recommended for groves receiving standard irrigation in the Vero Beach area. No adjustments in herbicide or pest control practices were made initially for the reclaimed wastewater treatments. However, after observing the influence of high rates of reclaimed wastewater application on weed growth some changes in herbicide practices were made which included use of less water soluble materials and more frequent spot sprays.

Weather data

Weather data were collected using a Campbell Scientific, Inc. remote weather station (Logan, UT). Temperature (average, maximum and minimum) and rainfall data were collected daily (Figs. 3.1-3).

Statistical analysis

Experiments were analyzed using the SAS general linear model (GLM) procedure and analysis of variance (ANOVA). Visual ratings and trunk diameter values were analyzed using analysis of covariance to standardize differences in

Fig. 3.1. Mean soil moisture content determined by neutron probe readings taken at a depth of 23 cm (A). Daily rainfall (B) for 1991, Vero Beach, Fla. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$

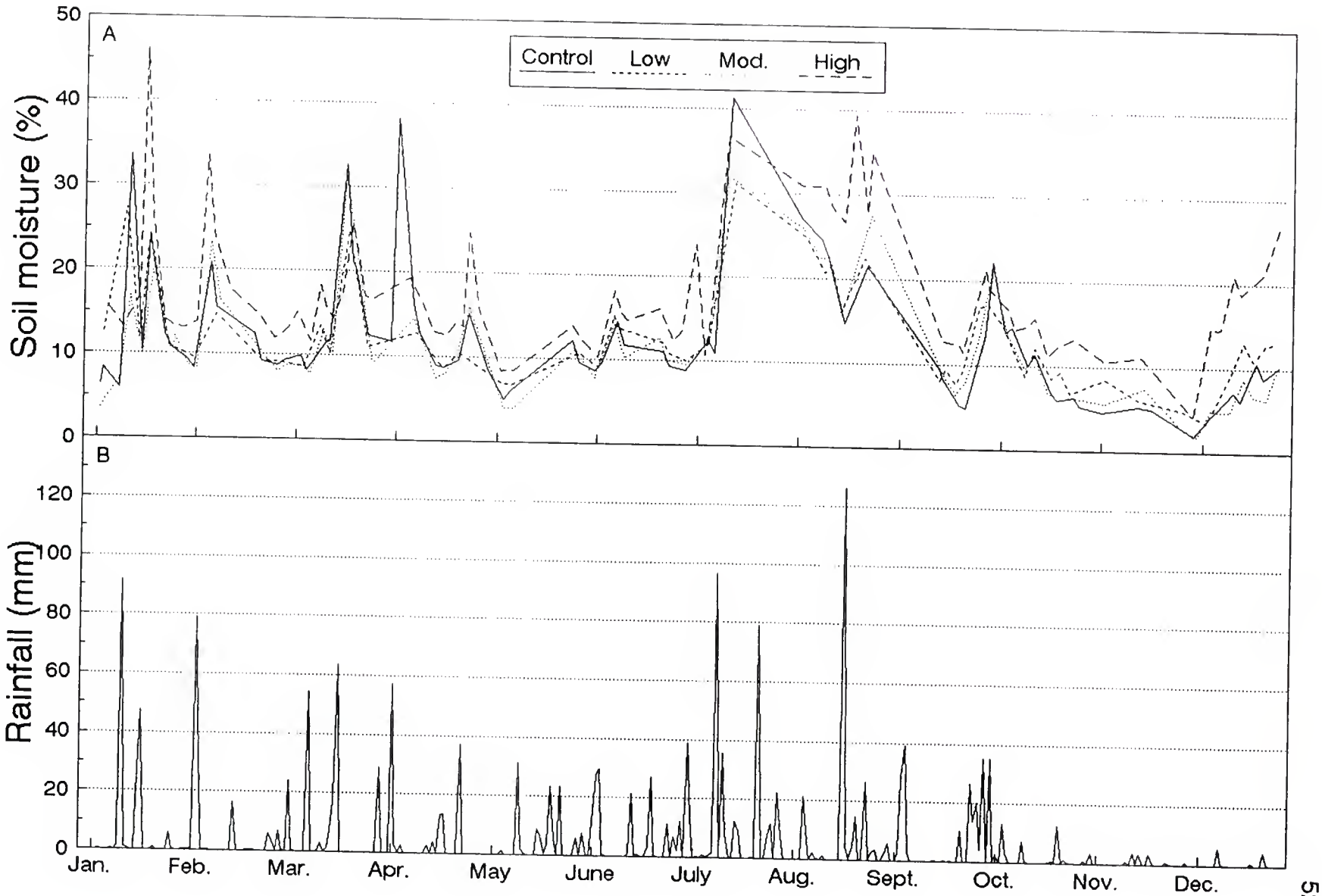

A
Control
Low
Mod.
High
Soil moisture (%)
50
40
30
20
10
0
B
Rainfall (mm)
120
100
80
60
40
20
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

Fig. 3.2. Mean soil moisture content determined by neutron probe readings taken at a depth of 23 cm (A). Daily rainfall (B) for 1992, Vero Beach, Fla. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$

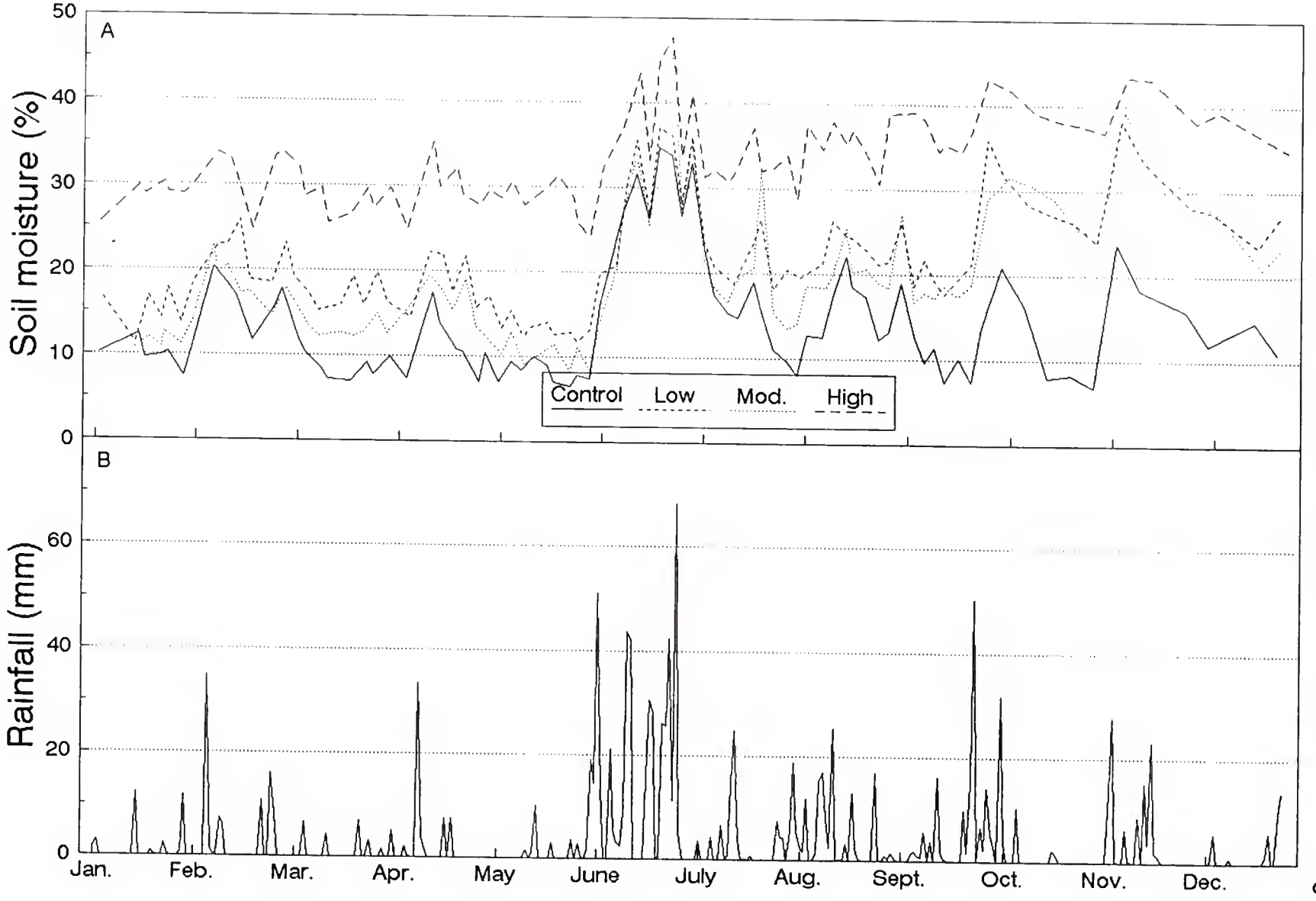
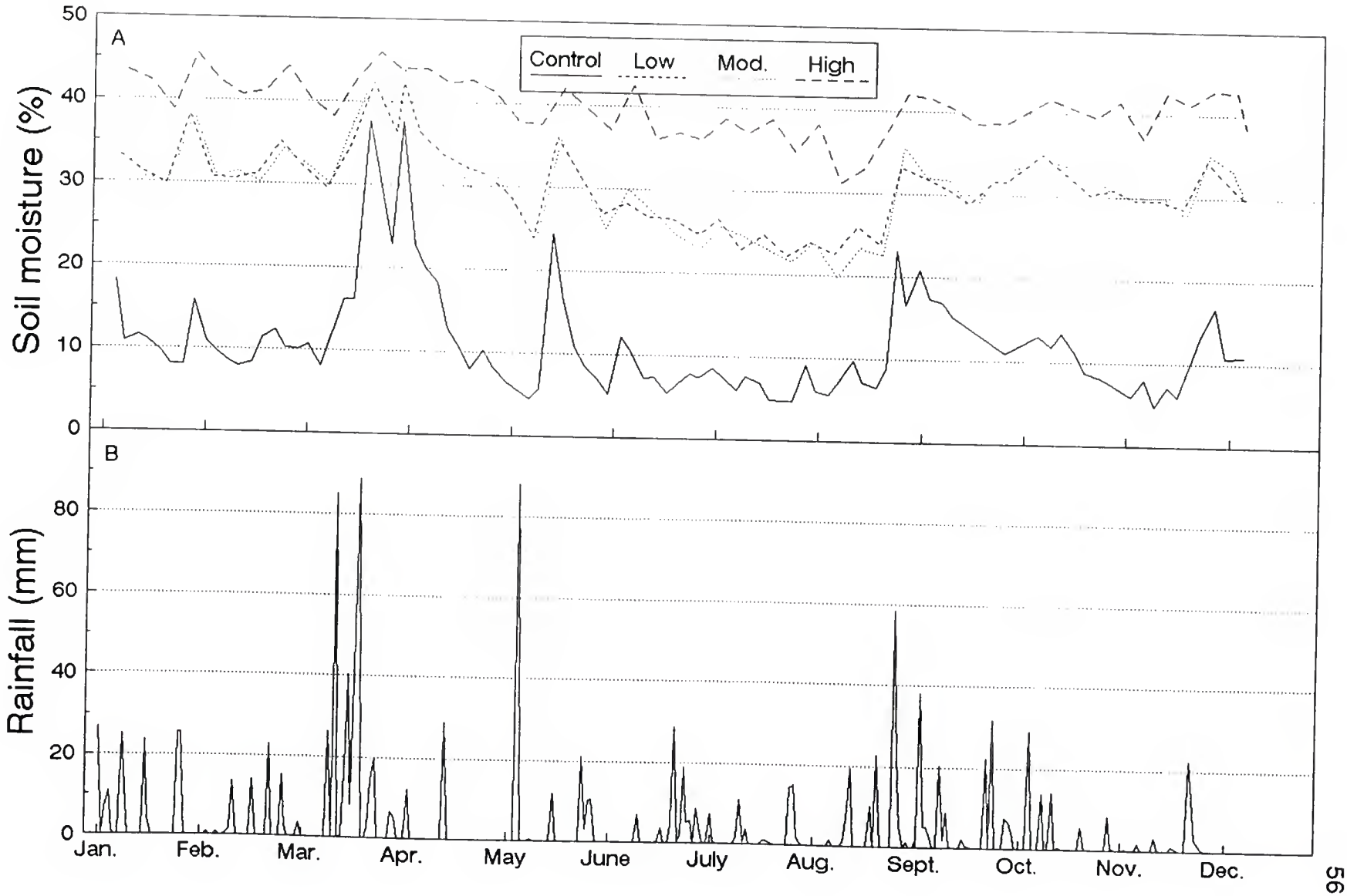

A
Soil moisture (%)
50
40
30
20
10
0
Control
Low
Mod.
High
B
Rainfall (mm)
60
40
20
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

Fig. 3.3. Mean soil moisture content determined by neutron probe readings taken at a depth of 23 cm (A). Daily rainfall (B) for 1993, Vero Beach, Fla. Control = canal water, and reclaimed wastewater at low = 23.1 mm·wk-1, mod. = 30.7 mm·wk^{-1} and high = 38.6 mm·wk^{-1}


A
Control
Low
Mod.
High
Soil moisture (%)
50
40
30
20
10
0
B
Rainfall (mm)
80
60
40
20
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

initial tree measurements. Repeated measures analysis was used in analyzing fruit growth, fruit quality and weed intensity. Regression analysis and orthogonal contrasts were used to determine trends in the data and to separate means where appropriate.

Results and Discussion

Soil moisture content and rainfall

Soil moisture content and rainfall were monitored from 1991-93 (Figs. 3.1-3). In 1991, soil moisture content represented the combined readings from two separate experiments, this experiment in the south part of the grove and an other experiment in the north part of the grove. Although both experiments were conducted on the same soil types differences in drainage patterns and irrigation levels resulted in lower mean soil moisture content levels in 1991. Soil moisture content averaged 12.4%, 12.5%, 11.6% and 17.4% for beds receiving the canal water, low, moderate and high-reclaimed wastewater treatments, respectively (Fig. 3.1). The low soil moisture content for all beds in Dec. 1991 resulted from discontinuation of treatments from 25 Nov. to 16 Dec. to clean and repair the water furrows to improve drainage.

In 1992, soil moisture content data represent measurements from this experiment only. Beds receiving the canal water, low, moderate and high-reclaimed wastewater treatments averaged 13.9%, 21.5%, 19.5% and 33.3%

soil moisture content, respectively (Fig. 3.2). All reclaimed wastewater treated beds had a lower soil moisture content until July and Aug. 1992 compared to the rest of the year when soil moisture content began to increase. The increase in soil moisture content coincided with an increase in weed growth which may have impeded water furrow drainage.

Aluminum access tubes were added to the east and west ends of each of the control beds and the average of the three lowest soil moisture content measurements were used to more accurately control irrigation levels. Soil moisture content averaged 10.9%, 29.8%, 29.8% and 38.5% for beds receiving the canal water, low, moderate and high-reclaimed wastewater treatments, respectively (Fig. 3.3).

Soil moisture contents were consistently higher for the reclaimed wastewater treatments compared to the control. Beds receiving the low and moderate-reclaimed wastewater treatments had similar soil moisture contents which were lower than the high-reclaimed wastewater treated beds in 1992-93. The difference between beds receiving the low and moderate-reclaimed wastewater treatments and the high treatment resulted from more frequent applications at the high rate. The low and moderate-reclaimed wastewater treated beds were irrigated twice/wk, but the high-reclaimed wastewater beds which had a higher soil moisture content were irrigated three times/wk. Soil moisture content measurements were taken prior to irrigation so that the lowest soil moisture depletion level was measured. The longer durations between

irrigations for the low and moderate-reclaimed wastewater treatments allowed for greater soil moisture depletion. After periods of heavy rainfall, the control beds periodically showed higher soil moisture content than beds receiving reclaimed wastewater which was due to time measurements were taken after rainfall occurred.

Tree growth

Trees receiving moderate-reclaimed wastewater were in general more vigorous than those receiving the other treatments (Table 3.7); however, in 1992, all reclaimed wastewater treated trees were significantly more vigorous than trees receiving canal water. Results are similar to those observed for citrus growing on the Ridge area of Florida (Koo and Zekri, 1989; Wheaton and Parsons, 1993; Zekri and Koo, 1990; Zekri and Koo, 1993). However, in these studies no adjustment in fertilization rate was made to account for nutrients in the reclaimed wastewater. Consequently, both fertilizer and water levels were varied.

Trunk diameter also was similar in 1990, 91 and 92 for all treatments, however; in 1993, trees receiving low and moderate-reclaimed wastewater treatments had statistically greater trunk diameters than those receiving the canal water or high-reclaimed wastewater treatments although the increase was small (Table 3.8). Visual ratings and trunk diameter measurements suggest that trees receiving reclaimed wastewater at high rates may have been

Table 3.7. Reclaimed wastewater and canal water effects on vegetative growth and development of 'Redblush' grapefruit trees at Vero Beach, Fla., 1989-93.

Treatments	Visual rating[z]				
	28 Nov. 1989	13 Dec. 1990	16 May 1991	14 Sept. 1992	23 Dec. 1993
Control					
Canal water	5.1[x] (4.9)	5.1 (4.9)	5.2 (5.1)	5.3 (5.2)	5.5 (5.3)
Reclaimed wastewater					
Low - 23.1 mm·wk^{-1}	5.1 (5.0)	5.1 (5.2)	5.3 (5.4)	5.6 (5.7)	5.7 (5.9)
Mod. - 30.7 mm·wk^{-1}	5.1 (5.3)	5.5 (5.7)	5.8 (5.9)	6.1 (6.2)	6.4 (6.5)
High - 38.6 mm·wk^{-1}	5.1 (5.3)	5.3 (5.6)	5.4 (5.7)	5.7 (5.9)	5.6 (5.9)
Significance					
Treatment	NS	***	***	***	***
Contrasts					
CW vs. Low				*	
CW vs. Mod.		***	***	***	***
CW vs. High				**	
Low vs. Mod.		***	***	***	***
Low vs. High					
Mod. vs. High			***	**	***

[z] Visual ratings ranged from 1 (a poorly growing, unhealthy) to 8 (a healthy, vigorous).

[x] Numbers in parenthesis are actual means. Other numbers represent adjusted means from the analysis of covariance. Each number represents the mean of 12 samples/bed with four replicates/treatment.

NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3.8. Reclaimed wastewater and canal water effects on trunk diameter of 'Redblush' grapefruit trees at Vero Beach, Fla., 1990-93.

Treatments	Trunk diam (mm)[z]			
	Nov. 90	Sept. 91	Sept. 92	Nov. 93
Control				
Canal water	223[x] (206)	226 (211)	229 (213)	231 (218)
Reclaimed wastewater				
Low - 23.1 mm·wk^{-1}	223 (221)	229 (226)	231 (229)	236 (236)
Mod. - 30.7 mm·wk^{-1}	223 (229)	226 (231)	229 (236)	236 (241)
High - 38.6 mm·wk^{-1}	223 (234)	226 (239)	226 (241)	231 (244)
Significance				
Treatment	NS	NS	NS	*
Contrasts				
CW vs. Low				*
CW vs. Mod.				*
Low vs. High				*
Mod. vs. High				*

[z] Trunk diameter measurements were taken approximately 20 cm above ground level.
[y] Numbers in parenthesis are actual means. Other numbers represent adjusted means from the analysis of covariance. Each number represents the mean of 12 samples/bed with four replicates/treatment.
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

over-irrigated, although soil in the treated area was rarely anaerobic based on soil redox potential measurements (data not shown). Soil moisture content (Figs. 3.1-3), however, for the high-reclaimed wastewater treatment was consistently higher than for the other treatments. In addition, soil moisture content in the low and moderate-reclaimed wastewater treatments was typically higher than for the areas receiving canal water. Trees receiving canal water also had reduced growth compared to those in the low and moderate treatments, which in this instance was more likely due to water stress rather than to excess water.

Leaf nutrient concentrations

Macronutrients

Leaf tissue N was similar for all treatments in 1990 and 91 (Tables 3.9-10); however, in 1990 the leaf N was in the optimum range (2.5-2.7%) (Koo et al., 1984), whereas in 1991 leaf N was in the deficient range (<2.2%) (Koo et al., 1984). These deficient N levels were attributable to the higher than normal rainfall (Appendix A), which caused leaching of fertilizer from the root zone. Additionally, the wet soil conditions prevented a second fertilizer application. Boman (1993) observed a similar reduction of leaf N from excessive rainfall and leaching at an experiment near Ft. Pierce, Fla. In 1992 and 93, leaf N concentrations for trees receiving canal water were slightly but significantly higher than those for the reclaimed wastewater treatments (Tables 3.11-12). In

Table 3.9. Reclaimed wastewater and canal water effects on leaf tissue nutrient concentration of 'Redblush' grapefruit trees in Vero Beach, Fla. 1990.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	2.6	0.13	0.7	5.3	0.44	970	--[x]	121	51	16	20
Reclaimed wastewater											
Low - 23.1 $mm \cdot wk^{-1}$	2.6	0.12	0.7	5.1	0.45	918	--[x]	135	48	16	21
Mod. - 30.7 $mm \cdot wk^{-1}$	2.6	0.12	0.8	5.0	0.44	888	--[x]	135	48	17	23
High - 38.6 $mm \cdot wk^{-1}$	2.6	0.13	0.8	5.1	0.44	980	--[x]	111	49	14	21
Significance											
Treatment	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS

[z] Each number represents the mean of 100 leaves/bed from four beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1990.
[y] Trees received fungicide sprays which contained Cu.
[x] Missing data.
[NS] Nonsignificant.

Table 3.10. Reclaimed wastewater and canal water effects on leaf tissue nutrient concentration of 'Redblush' grapefruit trees in Vero Beach, Fla. 1991.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	1.8	0.09	0.7	5.4	0.49	675	100	121	57	13	19
Reclaimed wastewater											
Low - 23.1 $mm \cdot wk^{-1}$	1.8	0.09	0.8	5.3	0.48	760	115	147	56	13	20
Mod. - 30.7 $mm \cdot wk^{-1}$	1.8	0.09	0.7	5.3	0.47	730	132	154	59	15	21
High - 38.6 $mm \cdot wk^{-1}$	1.8	0.09	0.8	5.4	0.45	793	102	178	61	11	25
Significance											
Treatment	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Each number represents the mean of 100 leaves/bed from four beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1991.
[y] Trees received fungicide sprays which contained Cu.
[NS] Nonsignificant.

Table 3.11. Reclaimed wastewater and canal water effects on leaf tissue nutrient concentration of 'Redblush' grapefruit trees in Vero Beach, Fla. 1992.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	2.5	0.14	1.1	4.2	0.46	1284	103	292	91	20	37
Reclaimed wastewater											
Low - 23.1 $mm \cdot wk^{-1}$	2.4	0.14	1.0	4.8	0.50	1129	158	465	126	19	38
Mod. - 30.7 $mm \cdot wk^{-1}$	2.4	0.14	1.0	5.2	0.50	830	179	590	114	21	36
High - 38.6 $mm \cdot wk^{-1}$	2.3	0.14	1.2	4.3	0.47	1110	152	432	103	18	34
Significance											
Treatment	*	NS	NS	*	NS	NS	***	**	NS	NS	NS
Contrasts[x]											
CW vs. Low	*						**	**			
CW vs. Mod.	**			**			***	***			
CW vs. High	**						**	*			
Low vs. Mod.								*			
Mod. vs. High				**				*			

[z] Each number represents the mean of five leaves/tree from 12 trees/bed and four beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1992.
[y] Trees received fungicide sprays which contained Cu.
[x] Only significant contrast are presented.
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3.12. Reclaimed wastewater and canal water effects on leaf tissue nutrient concentration of 'Redblush' grapefruit trees in Vero Beach, Fla. 1993.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	2.5	0.13	1.0	4.7	0.50	1027	64	226	51	14	27
Reclaimed wastewater											
Low - 23.1 $mm \cdot wk^{-1}$	2.3	0.12	1.2	4.5	0.45	1126	139	279	51	14	28
Mod. - 30.7 $mm \cdot wk^{-1}$	2.4	0.12	1.2	4.2	0.41	1188	161	274	50	11	28
High - 38.6 $mm \cdot wk^{-1}$	2.4	0.14	1.3	4.2	0.39	1203	149	229	49	11	28
Significance											
Treatment	***	***	***	*	***	NS	***	NS	NS	***	NS
Contrasts											
CW vs. Low	***	*	**		*		***				
CW vs. Mod.	*		***	**	***		***			**	
CW vs. High	**		***	**	***		***			***	
Low vs. Mod.	*				*		***			**	
Low vs. High		***			**					***	
Mod. vs. High		**					*				

[z] Each number represents the mean of five leaves/tree from 12 trees/bed and four beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1993.
[y] Trees received fungicide sprays which contained Cu.
[NS,*,**,***] Nonsignificant of significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

1993, leaf N concentration was greater for trees receiving the moderate and high-reclaimed wastewater treatments than for those receiving the low levels. The differences in leaf N levels, however, were small and are probably not significant from a practical standpoint. In addition, lower than optimum leaf N concentrations may be desirable for the production of fresh market grapefruit in the Indian River area (Koo et al., 1984).

Leaf P concentrations were similar for all treatments in 1990, 91 and 92 (Tables 3.9-11). In 1990 and 92 leaf P concentrations were in the optimum range (0.12-0.16%) (Koo et al.,1984), however, in 1991 leaf P was in the low range (0.09-0.11%) (Koo et al.,1984), again due to excessive rainfall. Although there were statistically significant differences in leaf P among treatments in 1993, levels were within the optimum range (Table 3.12). Increases in leaf P are often associated with reclaimed wastewater irrigation as seen in citrus (Zekri and Koo, 1993), peaches (Basiouny, 1984), cherries (Neilsen et al., 1991), apples (Neilsen et al., 1989a) and grapes (Neilsen et al., 1989b). The low levels of P in the reclaimed wastewater could account for a lack of difference among treatments in this study.

Leaf K concentrations were similar for all treatments in 1990, 91 and 92 (Tables 3.9-11). In 1990 and 91, leaf K was in the deficient-low range (0.7-1.1%) (Koo et al., 1984), but increased to the optimum range (1.2-1.7%) in 1992 (Koo et al., 1984). Leaf K concentration was significantly higher for all reclaimed wastewater treatments than for the canal water treatment in 1993

(Table 3.12). Although the reclaimed wastewater contained about twice the level of K as the canal water differences in leaf K concentrations were not apparent until 1993.

Leaf Ca concentrations were similar for all treatments in 1990 and 91 (Tables 3.9-10). All leaf Ca concentrations were in the high range (5.0-6.9%) (Koo et al., 1984). In 1992, leaf Ca levels in trees receiving the moderate levels of reclaimed wastewater were significantly higher than for those receiving the canal water or high-reclaimed wastewater treatments. Leaf Ca concentrations were in the optimum range (3.0-4.9%) (Koo et al., 1984) (Table 3.11). In 1993, trees receiving canal water were significantly higher in leaf Ca than trees receiving moderate and high-reclaimed wastewater rates (Table 3.12); however, all treatments were within the optimum range.

Leaf Mg concentrations were similar for all treatments in 1990, 91 and 92 (Tables 3.9-11), with all concentrations within the optimum range (0.30-0.49%) (Koo et al., 1984). In 1993, trees receiving canal water had significantly higher leaf Mg levels than those receiving reclaimed wastewater, with the low-reclaimed wastewater treatment having significantly higher Mg levels than the moderate and high-reclaimed wastewater treatments (Table 3.12). Although, there were statistical differences, all leaf Mg levels were within the optimum range.

Micronutrients

Leaf boron (B) concentrations were not analyzed in 1990 (Table 3.9), but in 1991 all treatments produced similar leaf B concentrations (Table 3.10), which were in the low end of the high range (101-200 $\mu g \cdot g^{-1}$) (Koo et al., 1984). Trees irrigated with reclaimed wastewater showed a 50% increase in leaf B over the canal water treatments in 1992 (Table 3.11), but all leaf B levels were in the high range. In 1993, trees receiving reclaimed wastewater had twice the concentration of leaf B than those receiving canal water (Table 3.12). Irrigation at the moderate-reclaimed wastewater rate increased leaf B concentrations more than at the other two reclaimed wastewater rates. However, leaf B levels for the reclaimed wastewater treatments were within the high range. Reclaimed wastewater contained four times more B than the canal water which accounts for increased leaf B concentrations. However, leaf B concentrations were below toxic levels (> 250 $\mu g \cdot g^{-1}$) for citrus trees (Koo et al., 1984). Increases in leaf B due to reclaimed wastewater treatment is consistent with previous results on citrus (Zekri and Koo, 1993).

Leaf Na concentrations were similar for all treatments in all four years; however, leaf Na levels were lowest in 1991 (Tables 3.9-12) due to leaching of Na beyond the root zone by excessive rainfall. Leaf Cu concentrations were also similar for all treatments (Tables 3.9-12), but varied greatly from year-to-year due to the addition of Cu containing fungicide sprays applied for melanose and greasy spot control. Similarly, leaf Fe concentrations were

similar for all treatments for all four years (Tables 3.9-12), however, in 1990, 91 and 93, leaf Fe concentrations were in the low range (36-59 $\mu g \cdot g^{-1}$) (Koo et al., 1984), while in 1992 they were in the optimum range (60-120 $\mu g \cdot g^{-1}$) (Koo et al., 1984). Leaf Mn concentrations were similar for all treatments in 1990, 91 and 92 (Tables 3.9-11). Levels were in the deficient range (>17 $\mu g \cdot g^{-1}$) (Koo et al., 1984) in 1990 and 91, and the low range (18-24 $\mu g \cdot g^{-1}$) (Koo et al., 1984) in 1992. In 1993, trees receiving canal water and low-reclaimed wastewater treatments had significantly higher leaf Mn than those in the other treatments (Table 3.12), but all leaf Mn concentrations were in the deficient range. Leaf Zn concentrations were similar for all treatments in each year with levels in the low range (18-24 $\mu g \cdot g^{-1}$) in 1990 and 91 (Tables 3.9-10) and in the optimum range (25-100 $\mu g \cdot g^{-1}$) (Koo et al., 1984), in 1992 and 93 (Tables 3.11-12). The similar leaf Fe, Mn and Zn levels for all treatments may have resulted from the low levels of the elements in the reclaimed wastewater and canal water.

The accumulation of nutrients in leaf tissue in this experiment reflect the levels received from the reclaimed wastewater, canal water or supplemental fertilization. The results obtained here may not be comparable to other experiments due to the variability in nutrient content of reclaimed wastewater. In addition, the short duration of this experiment may not account for long-term accumulation of nutrients with continued reclaimed wastewater use. Omran et al. (1988) found that leaf nutrient levels tended to increase with increasing duration of reclaimed wastewater use.

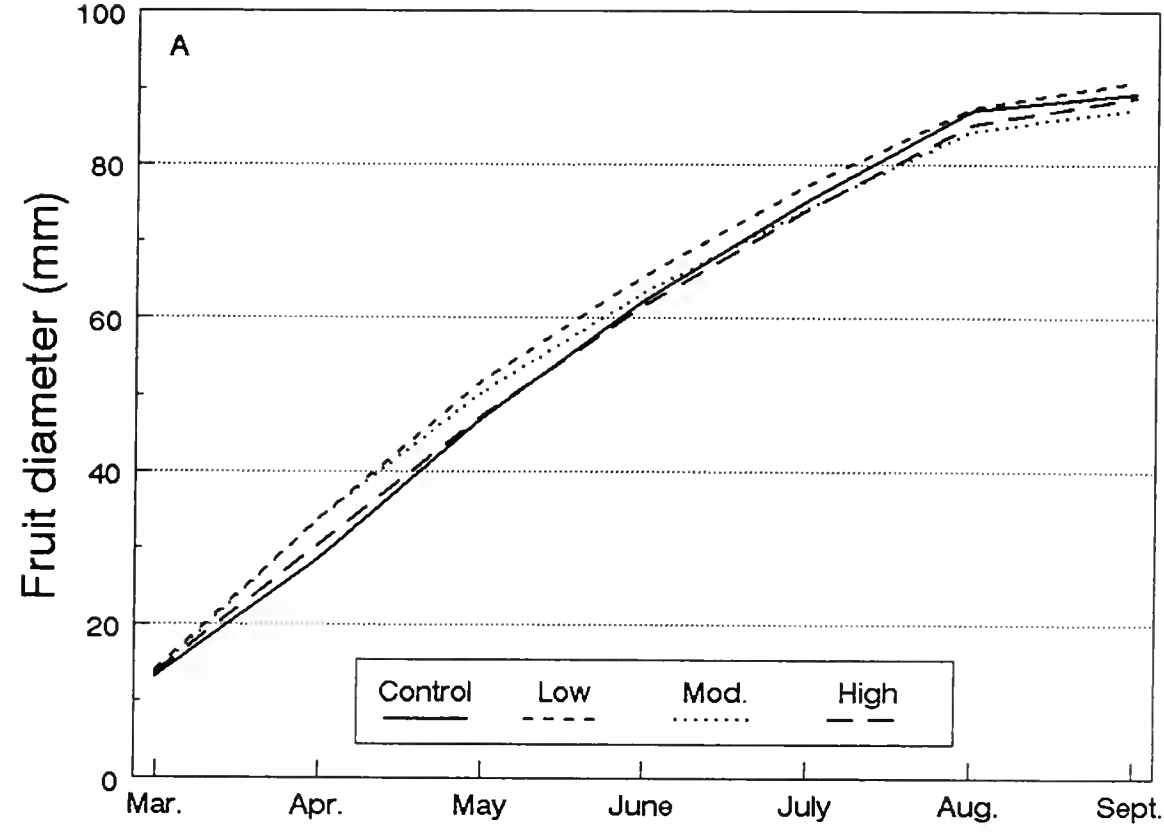
Fruit growth

Fruit growth patterns were similar for all treatments in 1990, 91 and 92, (Figs. 3.4-5), for all treatments and followed a typical sigmoid growth pattern for citrus fruit (Bain, 1958). In contrast, in 1993 trees receiving reclaimed wastewater had significantly larger fruit than those receiving canal water (Fig. 3.5B). The lack of difference in fruit growth in 1991 may have been attributed to above normal rainfall during the summer (Fig. 3.1).

Fruit weight for trees receiving reclaimed wastewater treatments was significantly greater than for those receiving canal water in 1991-92 (Fig. 3.6A). Fruit weight of trees receiving canal water was significantly less than for the other treatments from Aug.-Nov., but was similar from Dec.-Feb. Similarly, in 1992-93 fruit weight was significantly greater for reclaimed wastewater treatments compared to the canal water treatment (Fig. 3.7A). However, fruit weight for the reclaimed wastewater treatments was significantly greater than the canal water treatment for Oct. and Nov.; fruit weight was similar from Dec.-Feb. In 1993-94, fruit weight for the reclaimed wastewater treatments was significantly greater than for those in the canal water treatment (Fig. 3.8A).

Juice weight exhibited a similar trend to fruit weight. Fruit from trees receiving reclaimed wastewater had significantly higher juice weight than those receiving canal water in all three seasons (Figs. 3.6B-8B). In 1991-92, juice weight decreased for trees receiving canal water until December, but juice weight was similar for all treatments by Jan. and Feb. In 1992-93, fruit from

Fig. 3.4. Reclaimed wastewater and canal water effects on fruit growth of 'Redblush' grapefruit at Vero Beach, Fla., 1990 (A) and 91 (B). Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Means of eight fruit/tree for four trees/bed for four beds/treatment. There were no significant differences among treatments in both years. (A) Fruit growth 1990, $y = 12.87 + 21.02x - 1.35x^2$; $R^2 = 0.99$ all treatments pooled and (B) Fruit growth 1991, $y = 40.65 + 16.36x - 1.24x^2$; $R^2 = 0.97$ all treatments pooled.


A
Fruit diameter (mm)
100
80
60
40
20
0
Control
Low
Mod.
High
Mar.
Apr.
May
June
July
Aug.
Sept.

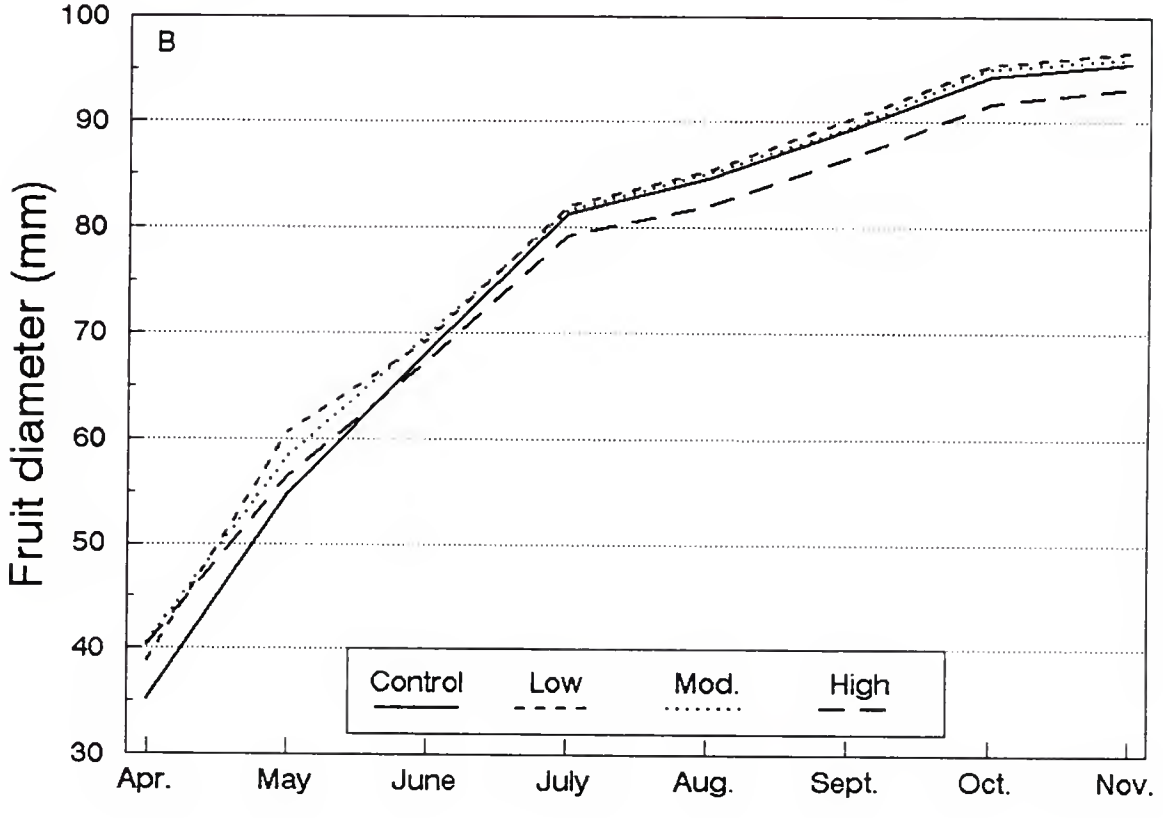
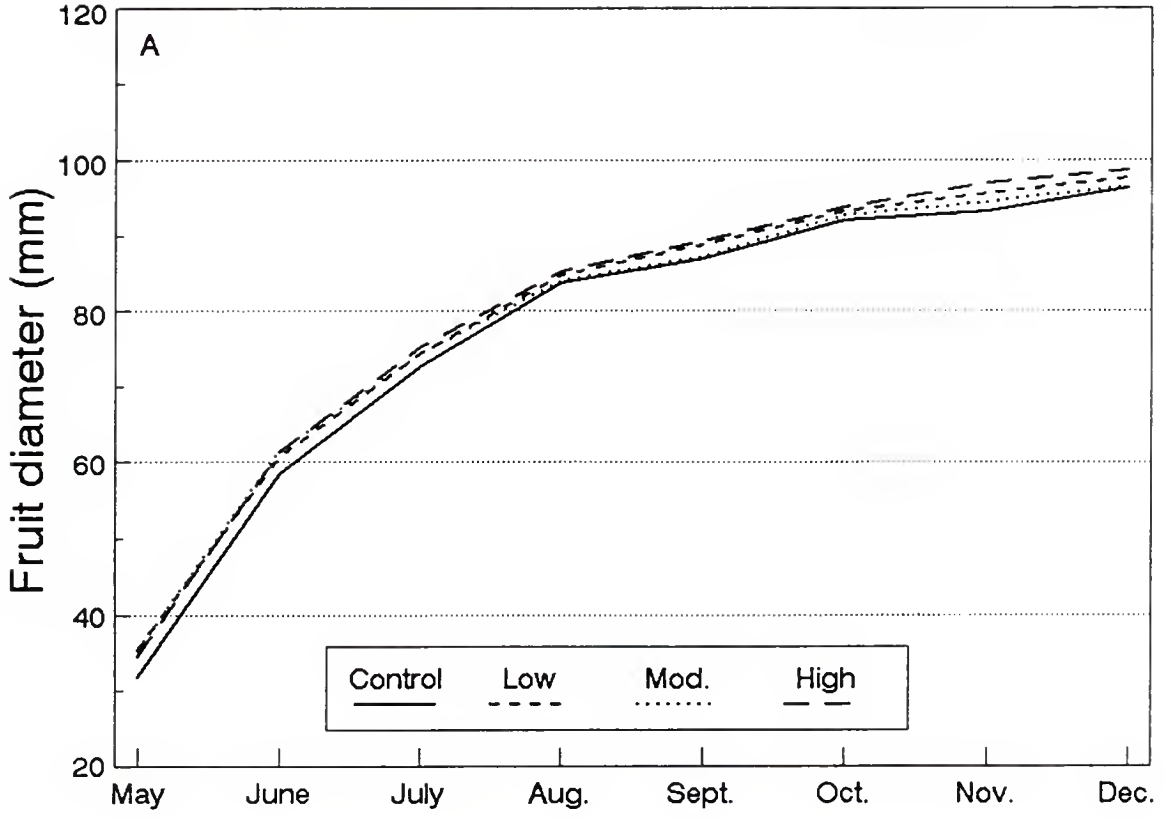

B
Fruit diameter (mm)
100
90
80
70
60
50
40
30
Control
Low
Mod.
High
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.

Fig. 3.5. Reclaimed wastewater and canal water effects on fruit growth of 'Redblush' grapefruit at Vero Beach, Fla., 1992 (A) and 93 (B). Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Means of eight fruit/tree for four trees/bed for four beds/treatment. (A) There was no significant difference among treatments in 1992,. $y = 38.38 + 19.95x - 1.70x^2$; $R^2 = 0.97$. (B) Pooled reclaimed wastewater treatments were not significantly different but differed from canal water, P = 0.06, reclaimed wastewater $y = 38.18 + 19.01x - 1.74x^2$; $R^2 = 0.99$; canal water $y = 41.89 + 19.03x - 1.72x^2$; $R^2 = 0.97$.


A
Fruit diameter (mm)
120
100
80
60
40
20
Control
Low
Mod.
High
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

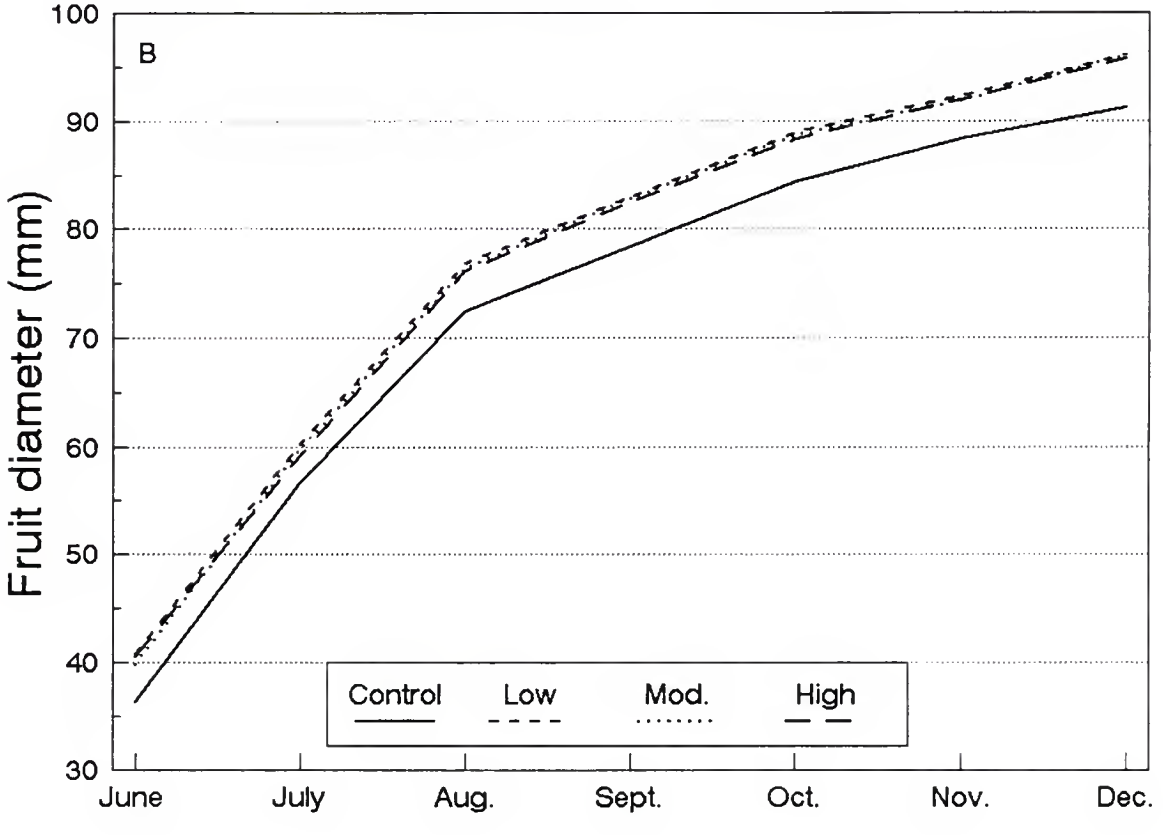

B
Fruit diameter (mm)
100
90
80
70
60
50
40
30
Control
Low
Mod.
High
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

Fig. 3.6. Reclaimed wastewater and canal water effects on fruit and juice weight and peel thickness of 'Redblush' grapefruit at Vero Beach, Fla., 1991-92. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Mean of 10 fruit/tree for four trees/bed for four beds/treatment. (A) Fruit weight for low, mod. and high reclaimed wastewater treatments differed significantly from canal water at P = 0.006, 0.019 and 0.078, respectively. Monthly analysis of variance were nonsignificant from Dec.-Feb. $y = 290.08 + 49.93x - 3.49x^2$; $R^2 = 0.73$ for the canal water; $y = 321.28 + 44.25x - 3.12x^2$; $R^2 = 0.75$ all reclaimed wastewater treatments pooled. (B) Fruit juice weight for low, mod. and high reclaimed wastewater treatments was significantly different from canal water at P = 0.003, 0.002 and 0.002, respectively. Monthly analysis of variance were nonsignificant from Dec.-Feb. $y = 138.38 + 44.97x - 3.20x^2$; $R^2 = 0.84$ for the canal water treatment; $y = 159.10 + 43.63x - 3.19x^2$; $R^2 = 0.89$ all reclaimed wastewater treatments pooled. (C) Fruit peel thickness was not significantly different among treatments. $y = 5.99 - 0.77x + 0.07x^2$; $R^2 = 0.77$ for all treatments pooled.

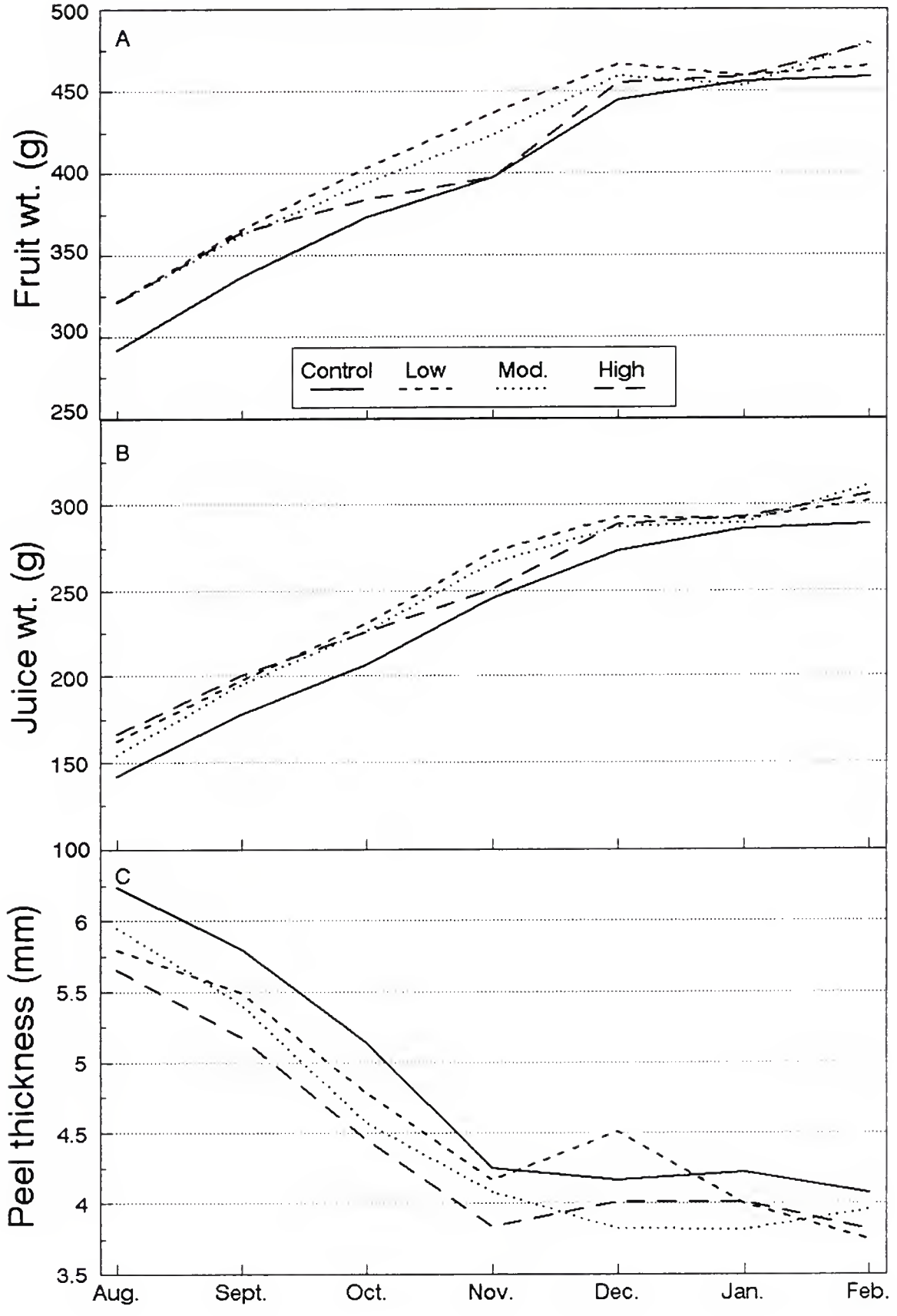

A
B
C
Fruit wt. (g)
Juice wt. (g)
Peel thickness (mm)
Control
Low
Mod.
High
500
450
400
350
300
250
300
250
200
150
100
6
5.5
5
4.5
4
3.5
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.

Fig. 3.7. Reclaimed wastewater and canal water effects on fruit and juice weight and peel thickness of 'Redblush' grapefruit at Vero Beach, Fla., 1992-93. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Mean of 10 fruit/tree for four trees/bed for four beds/treatment. (A) Fruit weight for trees receiving canal water were significantly different from the low, mod. and high reclaimed wastewater trees at P = 0.02, 0.03 and 0.09, respectively. Canal water trees were significant from reclaimed wastewater trees in Nov. and Dec. in monthly analysis of variation. $y = 315.97 + 30.05x + 0.13x^2$; $R^2 = 0.65$ for the canal water treatment; $y = 325.72 + 45.11x + 3.91x^2$; $R^2 = 0.68$ for all treatments pooled. (B) Fruit juice weight for the canal water trees was significant different from the low, mod. and high reclaimed wastewater trees at P = 0.01, 0.06 and 0.07, respectively. Juice weight for canal water trees was significantly different from reclaimed wastewater trees in Nov. and Dec. in monthly analysis of variation. $y = 148.89 + 32.36x - 1.22x^2$; $R^2 = 0.86$ for the canal water treatment; $y = 152.47 + 39.10x - 2.43x^2$; $R^2 = 0.88$ for the reclaimed wastewater treatments pooled. (C) Fruit peel thickness was not significantly different among treatments. $y = 5.29 - 0.65x + 0.08x^2$; $R^2 = 0.69$ for all treatments pooled.

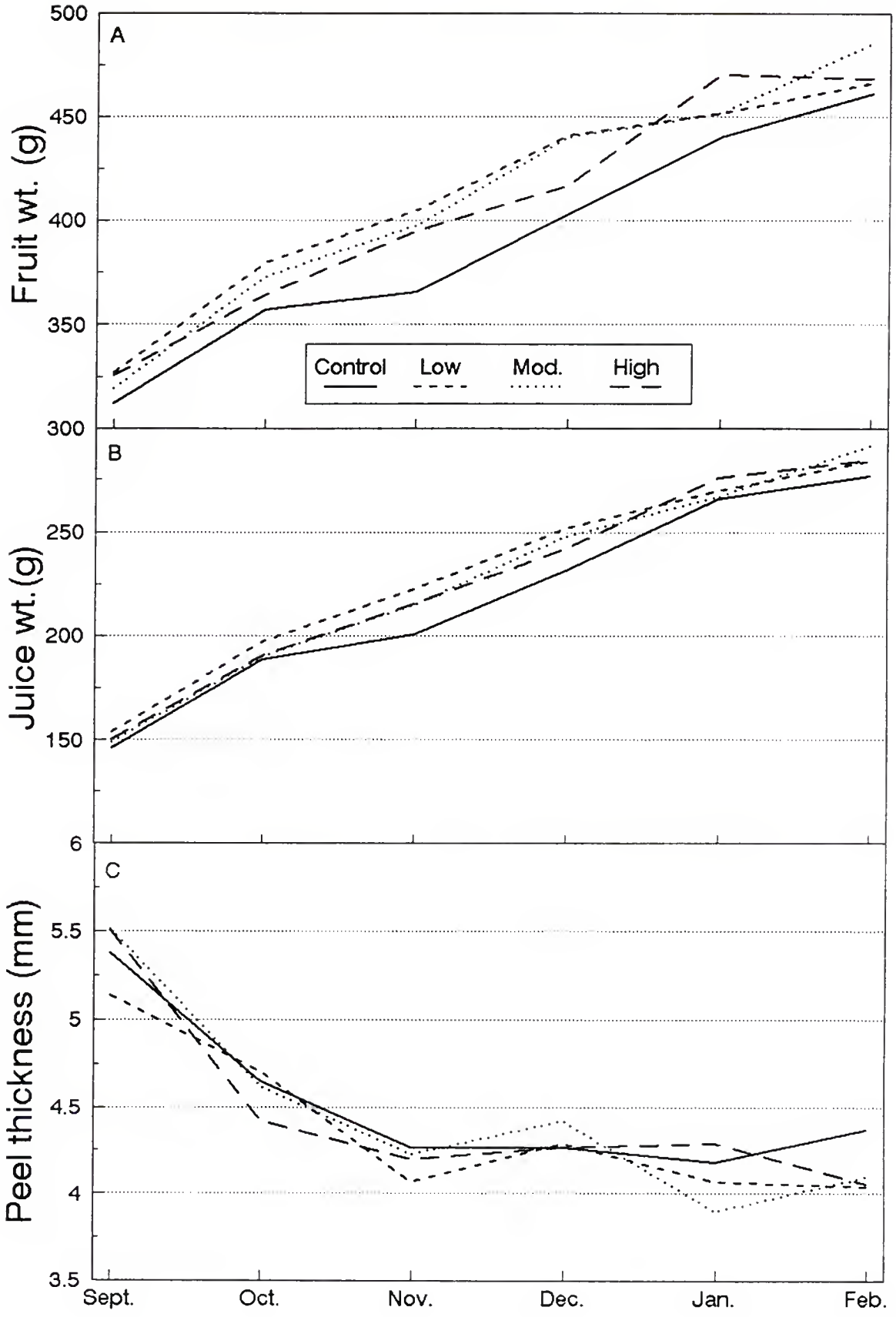
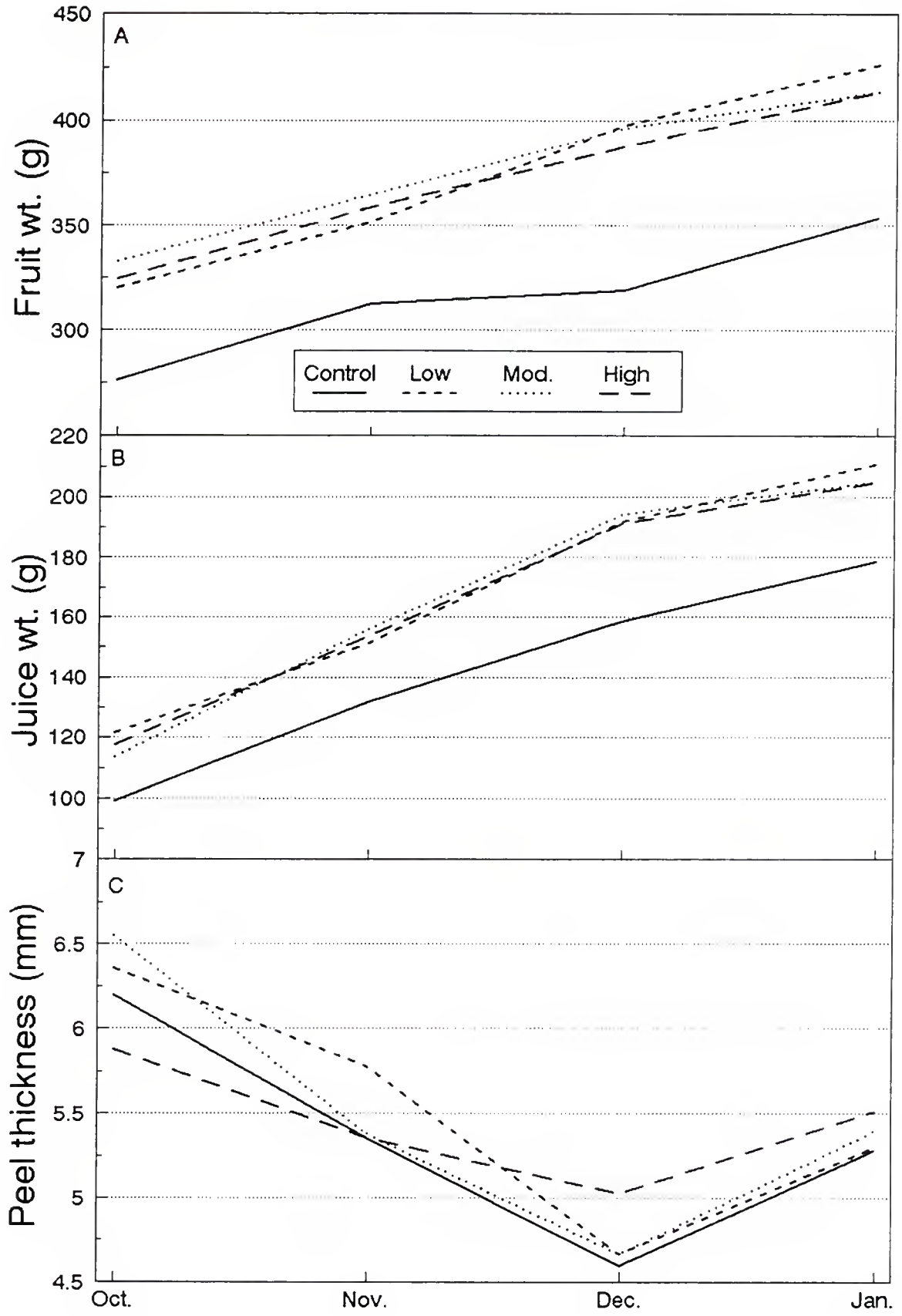

A
B
C
Fruit wt. (g)
Juice wt. (g)
Peel thickness (mm)
Control
Low
Mod.
High
500
450
400
350
300
250
200
150
6
5.5
5
4.5
4
3.5
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.

Fig. 3.8. Reclaimed wastewater and canal water effects on fruit and juice weight and peel thickness of 'Redblush' grapefruit at Vero Beach, Fla., 1993-94. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Mean of 10 fruit/tree for four trees/bed for four beds/treatment. (A) Fruit weight from trees receiving canal water were significantly different from trees receiving reclaimed wastewater $P \leq 0.001$. $y = 279.32 + 25.21x - 0.41x^2$; $R^2 = 0.44$ for the canal water treatment; $y = 325.31 + 37.86x - 2.28x^2$; $R^2 = 0.49$ for all reclaimed wastewater treatments pooled. (B) Fruit juice weight for trees receiving canal water were significantly different from trees receiving reclaimed wastewater $P \leq 0.001$. $y = 99.37 + 35.64x - 3.05x^2$; $R^2 = 0.82$ for the canal water treatment; $y = 116.38 + 46.79x - 5.38x^2$; $R^2 = 0.72$ for all reclaimed wastewater treatments pooled. (C) Fruit peel thickness was not significantly different among treatments. $y = 6.31 - 1.38x + 0.35x^2$; $R^2 = 0.56$ for all treatments pooled.


A
B
C
Fruit wt. (g)
Juice wt. (g)
Peel thickness (mm)
Control
Low
Mod.
High
450
400
350
300
220
200
180
160
140
120
100
7
6.5
6
5.5
5
4.5
Oct.
Nov.
Dec.
Jan.

trees receiving canal water had significantly lower juice weight in Nov. and Dec.; however, juice weight was similar for all other months. Juice weight of trees receiving reclaimed wastewater was significantly greater for the entire season in 1993-94.

Peel thickness was similar for all treatments in each of the three years (Figs. 3.6C-8C) even though juice and fruit weight differed for some treatments. This similarity may have been due to similar K levels for all treatments. Potassium has a significant regulatory effect on peel thickness in citrus (Embleton et al., 1973).

Fruit quality

Total soluble solids (TSS) were significantly lower for trees receiving moderate-reclaimed wastewater compared with the other treatments in 1991-92 (Fig. 3.9A). However, from December until harvest all treatments had similar fruit TSS. In 1992-93, fruit had similar TSS for all treatments (Fig. 3.10A). In 1993-94, again fruit from the moderate-reclaimed wastewater treatment were significantly lower in TSS compared to fruit receiving canal water (Fig. 3.11A). The variable effects of high irrigation levels on TSS are consistent with results obtained in other studies (Boman, 1992; Zekri and Koo, 1993).

Juice titratable acidity (TA) levels were similar for all treatments in 1991-92 (Fig. 3.9B) and 1993-94 (Fig. 3.11B), but in 1992-93 TA of trees receiving the canal water was significantly higher than for those receiving the reclaimed

Fig. 3.9. Reclaimed wastewater and canal water effects on fruit total soluble solids (TSS), titratable acidity (TA) and TSS:TA ratio of 'Redblush' grapefruit at Vero Beach, Fla., 1991-92. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Mean of 10 fruit/tree for four trees/bed for four beds/treatment. (A) Fruit TSS for trees receiving the mod. reclaimed wastewater was significantly different from other treatments. Fruit TSS for trees receiving the mod. reclaimed wastewater were similar to other treatments from Dec.-Feb. in monthly analysis of variation. $y = 9.20 + 0.06x + 0.04x2$; $R^2 = 0.79$ for the mod. reclaimed wastewater treatment; $y = 9.39 + 0.06x + 0.04x^2$; $R^2 = 0.72$ for all treatments pooled. (B) Fruit TA was not significantly different among treatments. $y = 1.67 - 0.28x + 0.03x^2$; $R^2 = 0.87$ for all treatments pooled. (C) Fruit TSS:TA ratio was not significantly different among treatments. $y = 5.46 + 1.43x - 0.11x^2$; $R^2 = 0.89$ for all treatments pooled.

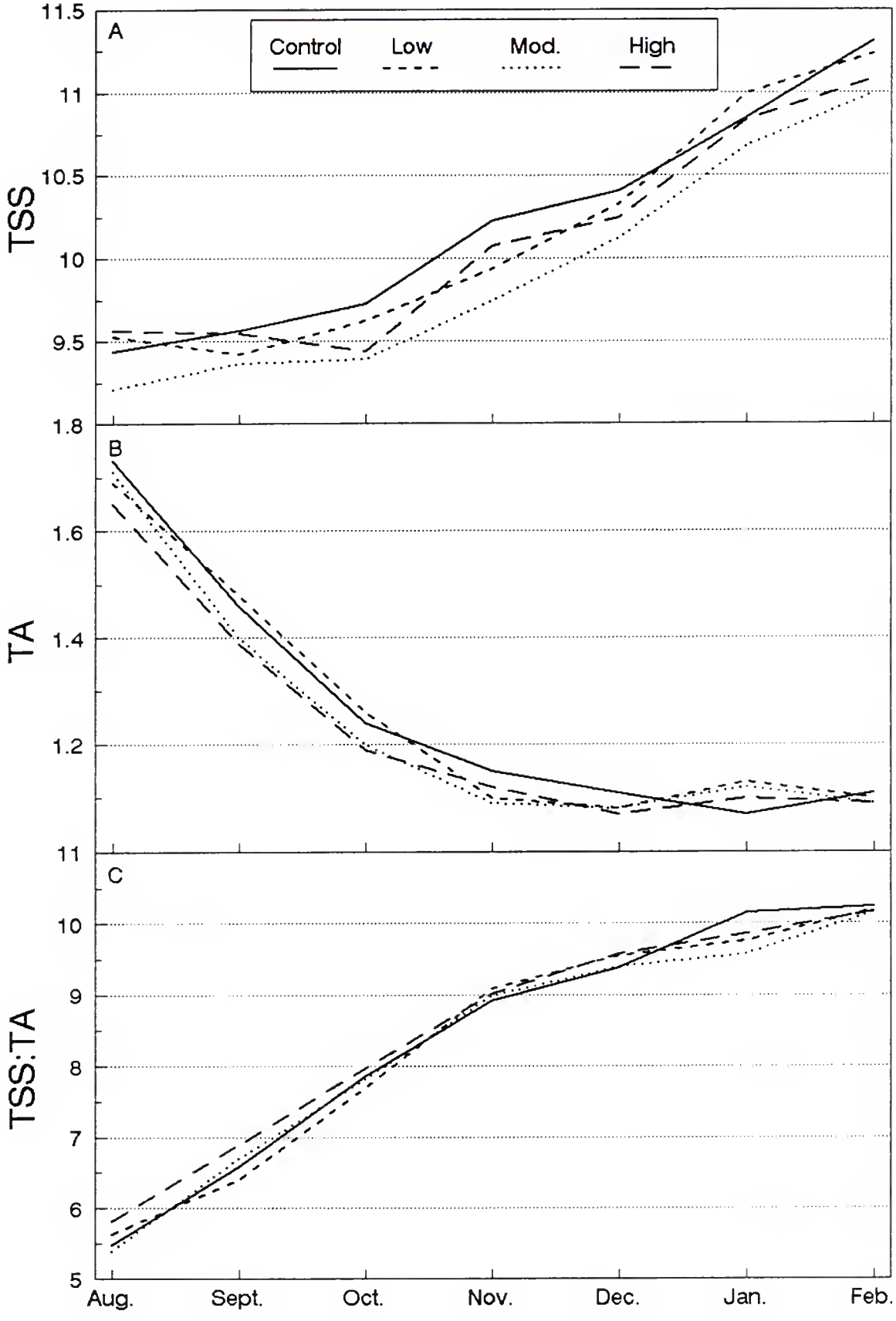

A
Control
Low
Mod.
High
TSS
11.5
11
10.5
10
9.5
1.8
B
TA
1.6
1.4
1.2
11
C
TSS:TA
10
9
8
7
6
5
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.

Fig. 3.10. Reclaimed wastewater and canal water effects on fruit total soluble solids (TSS), titratable acidity (TA) and TSS:TA ratio of 'Redblush' grapefruit at Vero Beach, Fla., 1992-93. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Mean of 10 fruit/tree for four trees/bed for four beds/treatment. (A) Fruit TSS was not significantly different among treatment. $y = 5.83 + 0.64x + 0.006x^2$; $R^2 = 0.89$ for all treatments pooled. (B) Fruit TA for trees receiving canal water were significantly different from trees receiving reclaimed wastewater. Fruit TA for trees receiving canal water were significant from the reclaimed wastewater trees from Nov. - Feb. in monthly analysis of variation. $y = 1.59 - 0.07x + 0.0008x^2$; $R^2 = 0.55$ for the canal water treatment; $y = 1.57 - 0.12x + 0.008x^2$; $R^2 = 0.79$ for all reclaimed wastewater treatments pooled. (C) Fruit TSS:TA ratio for trees receiving canal water was significantly different from trees receiving low and mod. reclaimed wastewater. Fruit TSS:TA ratio for trees receiving canal water were significant from trees receiving reclaimed wastewater from Dec.-Feb. in monthly analysis of variation. $y = 3.83 + 0.42x + 0.06x^2$; $R^2 = 0.78$ for the canal water treatment; $y = 3.72 + 0.71x + 0.04x^2$; $R^2 = 0.86$ for all reclaimed wastewater treatments pooled.

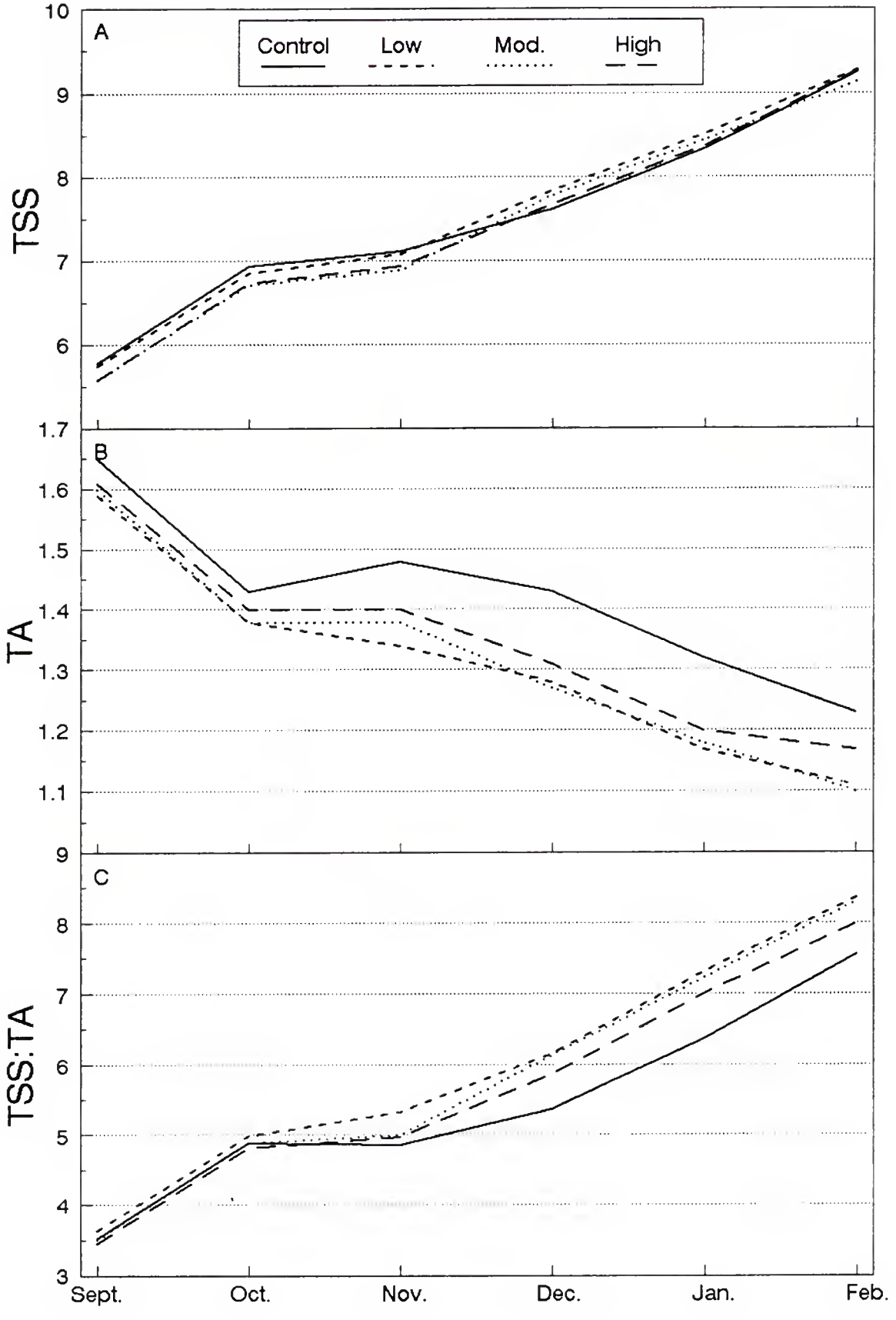
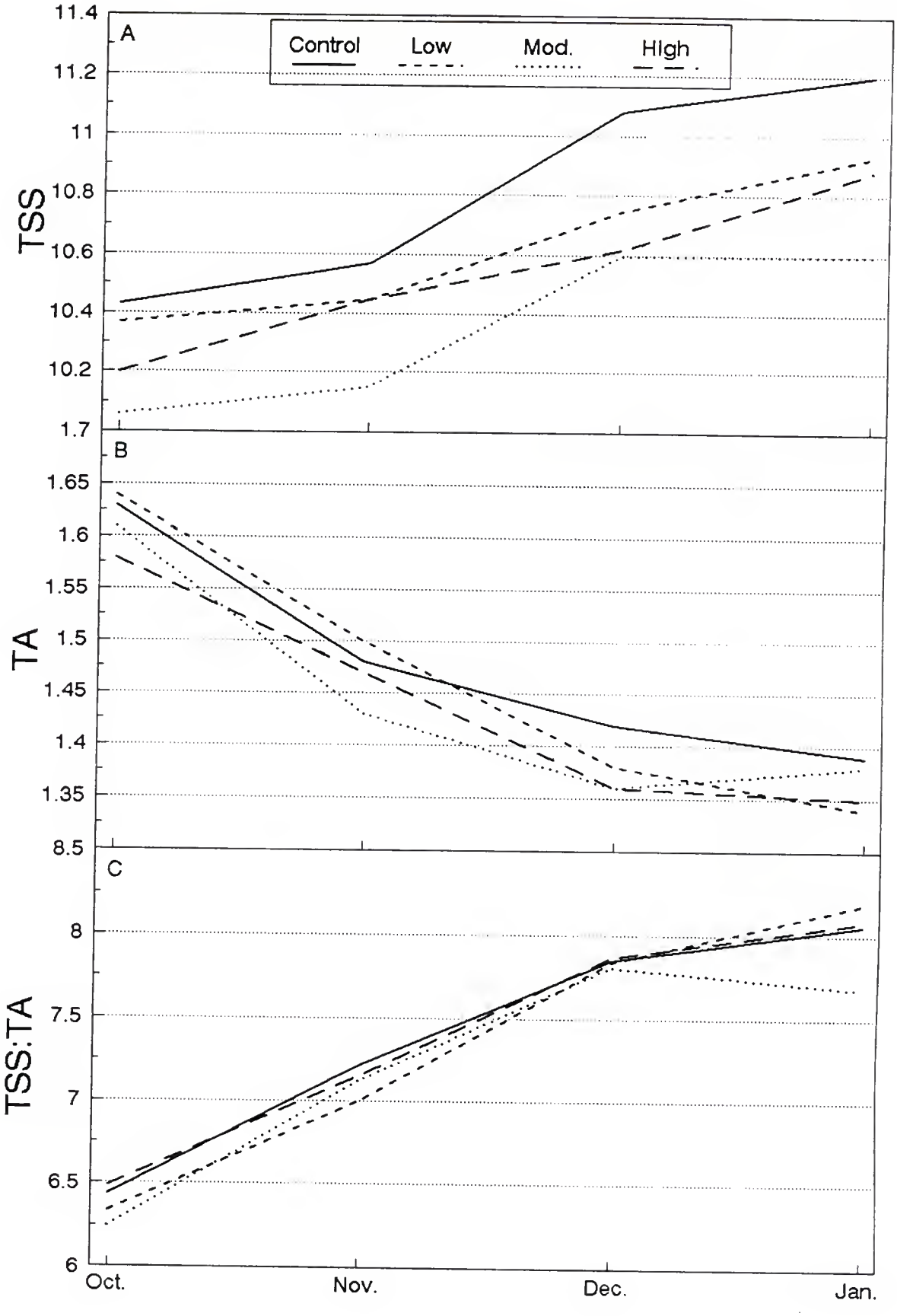

A
Control
Low
Mod.
High
TSS
10
9
8
7
6
1.7
B
TA
1.6
1.5
1.4
1.3
1.2
1.1
9
C
TSS:TA
8
7
6
5
4
3
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.

Fig. 3.11. Reclaimed wastewater and canal water effects on fruit total soluble solids (TSS), titratable acidity (TA) and TSS:TA ratio of 'Redblush' grapefruit at Vero Beach, Fla., 1993-94. Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Mean of 10 fruit/tree for four trees/bed for four beds/treatment. (A) Fruit TSS for tree receiving canal water were significantly different from trees receiving mod. and high reclaimed wastewater. $y = 10.39 + 0.29x - 0.004x^2$; $R^2 = 0.39$ for the canal water treatment; $y = 10.19 + 0.20x + 0.002x^2$; $R^2 = 0.21$ for all reclaimed wastewater treatments pooled. (B) Fruit TA was not significantly different among treatments. $y = 1.61 - 0.19x + 0.03x^2$; $R^2 = 0.53$ for all treatments pooled. (C) Fruit TSS:TA ratio was not significantly different among treatments. $y = 6.35 + 0.99x - 0.14x^2$; $R^2 = 0.71$ for all treatments pooled.


A
Control
Low
Mod.
HIgh
TSS
11.4
11.2
11
10.8
10.6
10.4
10.2
1.7
B
TA
1.65
1.6
1.55
1.5
1.45
1.4
1.35
8.5
C
TSS:TA
8
7.5
7
6.5
6
Oct.
Nov.
Dec.
Jan.

wastewater treatments (Fig. 3.10B). For 'Marsh' grapefruit trees irrigated above optimum levels, fruit TA was diluted in one of four years (Koo, 1985b). Likewise, on flatwoods soils Graser and Allen (1987) observed no dilution in fruit TA associated with irrigation. Similarly, Boman (1992) found no difference in TA for trees irrigated at 30% or 50% soil water depletion. It appears from this study that high rates of reclaimed wastewater do not consistently dilute fruit TA. In contrast, fruit TA was consistently lower for trees receiving reclaimed wastewater than well water in the Conserv II project (Zekri and Koo, 1993).

In addition, B has been shown to improve fruit quality in B deficient trees (Smith, 1954; Smith, 1956). Smith (1973) showed that B applied to the soil or as foliar sprays increased fruit acidity. However in this study, trees which received reclaimed wastewater had higher leaf B levels than the control trees, but fruit acidity was not affected. However, in 1992-93, the trees receiving reclaimed wastewater which had higher leaf B levels had lower fruit acidity levels. In this experiment it appears that irrigation may have affected fruit acidity more than B.

Fruit TSS:TA ratio was similar for all treatments in 1991-92 (Fig. 3.9C). In 1992-93, fruit from the low and moderate-reclaimed wastewater treatments had a significantly higher TSS:TA ratio than those from the canal water treatment (Fig. 3.10C). This difference occurred from December until harvest and was due to the decrease in fruit TA. In 1993-94, fruit TSS:TA ratio was again similar for all treatments (Fig. 3.11C). Therefore irrigation had a tendency to increase

fruit TSS:TA ratios. Zekri and Koo (1993) also observed increases in fruit TSS:TA ratios in four of six years when using heavy applications of reclaimed wastewater.

Reclaimed wastewater irrigation had inconsistent effects on fruit TSS, TA and TSS:TA. However, use of reclaimed wastewater for irrigation may actually be beneficial. Even though reclaimed wastewater treatments at times diluted fruit TSS and TA, the fruit TSS:TA ratios were actually higher for fruit from the reclaimed wastewater than the canal water treatment as seen in 1992-93 (Fig. 3.11). This fruit attained minimum maturity standards about two to three weeks earlier for reclaimed wastewater vs. canal water treatments.

Heavy metals in fruit

No accumulation of Cd, Ni or Pb was detected in the fruit in 1992 or 93 (data not shown). This finding is not surprising since the reclaimed wastewater had only non-detectable or trace amounts of heavy metals which is typical of non-industrial wastewater. Therefore, use of reclaimed wastewater of this quality poses no threat to citrus trees or consumers from heavy metal accumulation.

Yields

Due to a dual-bloom season, fruit from the 1990-91 season were harvested in Oct. 1990 and again in June 1991. A moderate freeze of Dec.

1989 had caused two blooms to occur one in Feb. 1990 and a second in Mar.-Apr. 1990. Prior to implementation of the irrigation treatments, yields in 1990-91 were statistically similar for all beds averaging 196 kg/tree (Table 3.13). However, trees in the canal water treatments, which had been selected randomly, had numerically lower yields than the other trees. Thus, subsequent yields were analyzed by covariate analyses to adjust for this difference. The 1991-92 crop was harvested in Mar. 1992. Trees receiving low and moderate-reclaimed wastewater treatments produced significantly higher yields than those receiving canal water. Yield for the high-reclaimed wastewater trees was also greater than for canal water trees ($P \leq 0.14$), but was similar to the low and moderate-reclaimed wastewater treatments (Table 3.13). Harvest of the 1992-93 crop began in early Mar. 1993. On 13 Mar. 1993 a severe wind storm caused an estimated loss of 41 kg/tree for some of the trees. This estimate was added to the yield to adjust for these losses. Yield for the low, moderate and high-reclaimed wastewater treatments was significantly greater than for the trees receiving canal water at $P \leq 0.05$, 0.11 and 0.10, respectively (Table 3.13).

It is well documented that irrigation during the critical period from bloom through fruit set is important for increasing yield (Bielorai, 1978; Koo, 1963; Koo and Sites, 1955). The above optimum levels of reclaimed wastewater irrigation may have accounted for increases in yield in this study. Boman (1992) also found that for navel oranges growing on the flatwoods optimum

Table 3.13. Reclaimed wastewater and canal water effects on yield of 'Redblush' grapefruit trees at Vero Beach, Fla., 1990-94.

Treatments	Yield (kg/tree)			
	1990-91	1991-92	1992-93	1993-94
Control				
Canal water	196[z] (180)	155 (147)	233 (221)	132 (125)
Reclaimed wastewater				
Low - 23.1 mm·wk^{-1}	196 (196)	208 (208)	317 (317)	201 (201)
Mod. - 30.7 mm·wk^{-1}	196 (212)	208 (221)	309 (322)	212 (221)
High - 38.6 mm·wk^{-1}	196 (188)	192 (188)	293 (288)	185 (183)
Significance				
Treatment		0.16	0.22	0.12
Contrasts				
CW vs. Low		0.05	0.06	0.04
CW vs. Mod.		0.05	0.09	0.03
CW vs. High		0.14	0.15	0.11
Low vs. Mod.		NS	NS	NS
Low vs. High		NS	NS	NS
Mod. vs. High		NS	NS	NS

[z] Numbers in parenthesis are actual means. Other numbers represent adjusted means from analysis of covariance. Numbers represent the means of 58 trees/bed and four beds/treatment.
[NS] Nonsignificant.

irrigation tended to increase yield, though not statistically so. Although irrigation above the crop requirement increased yield, the increase was not economically justified due to pumping costs (Koo, 1963; Smajstrla and Koo, 1984). However, if reclaimed wastewater is provided free the increase in yields is justified. Similar increases in yield from reclaimed wastewater use were observed for citrus on the Ridge in the Conserv II project (Zekri and Koo, 1993). Nevertheless, our data suggest that application rates greater than 30.7 $mm \cdot wk^{-1}$ may decrease yields for the soil types used in this study.

Enteric viruses

An important concern related to the use of reclaimed wastewater is the potential health hazards posed by bacteria and viruses in the water. The water used in this project received secondary treatment and chlorination. Reclaimed wastewater analysis for enteroviruses averaged 195.5 PFU/liter for the influent, but < 0.003 PFU/liter for the effluent which was used for irrigation (Table 3.4). Influent levels varied greatly depending on the season, but levels in the effluent were very consistent. Furthermore, fruit from trees treated with high rates of reclaimed wastewater in the laboratory also had < 0.003 PFU/liter on the peel. Similar findings were made by the Florida State Dept. of Health (unpublished). Citrus fruit dipped directly into untreated wastewater had no enteric viruses in the fruit or on the peel following washing with standard packinghouse procedures. Moreover, the reclaimed wastewater in this study was applied

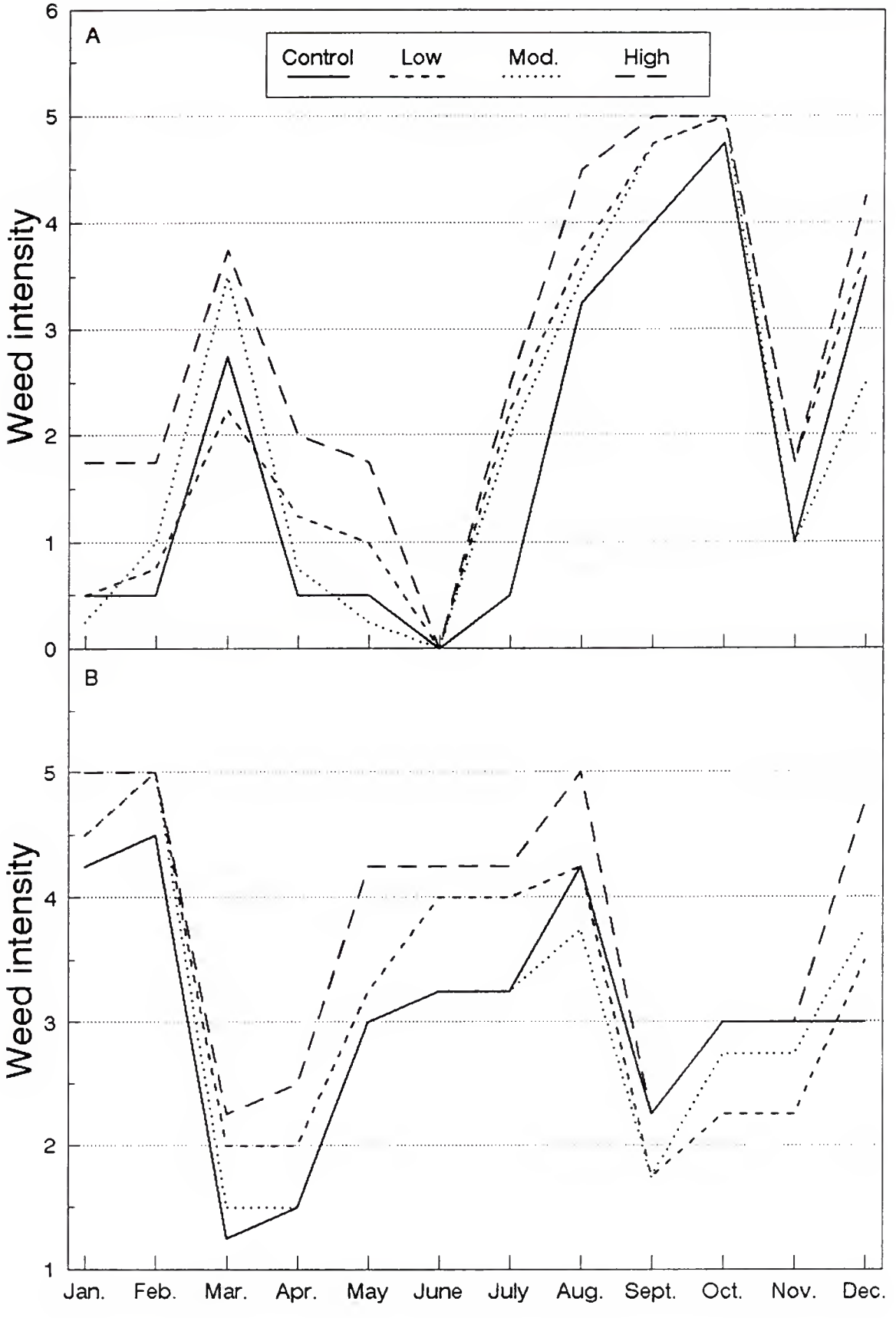
under tree to the soil and not directly to the fruit surfaces. Therefore, any risk to workers or consumers associated with use of reclaimed wastewater is extremely small.

Weed growth

Weed intensity in 1992-93 varied seasonally and with herbicide treatments. Decreases in weed intensity were associated with herbicide applications in 5 Mar., 15 May, 2 July, and 30 Sept., 1992 and 6 Feb., 27 May and 23 Aug. 1993. However, weed growth was nearly always greater on beds receiving reclaimed wastewater than canal water (Fig. 3.12). Weed intensity was greater in areas where trees had been removed or resets planted; however, weed growth was also greater under trees with full canopies. Increased weed growth has been associated with use of reclaimed wastewater for irrigation on the Ridge area of Florida (Wheaton and Parsons, 1993; Zekri and Koo, 1993). Application of high amounts of reclaimed wastewater provides abundant water and nutrients for weed growth. In addition, the heavy applications of reclaimed wastewater may leach herbicides from the soil. Weed growth, especially around microsprinklers, also interferes with water distribution and ground coverage (Koo and Smajstrla, 1984).

Irrigation of mature 'Redblush' grapefruit trees using reclaimed wastewater on Wabasso fine sands caused no deleterious affects when adequate drainage was provided. Tree growth, development and yields were

Fig. 3.12. Reclaimed wastewater and canal water effects on weed growth in the tree row for 'Redblush' grapefruit at Vero Beach, Fla., 1992 (A) and 93 (B). Control = canal water, and reclaimed wastewater at low = 23.1 $mm \cdot wk^{-1}$, mod. = 30.7 $mm \cdot wk^{-1}$ and high = 38.6 $mm \cdot wk^{-1}$. Rating was based on a scale of 0 (no weed growth) to 5 (>50% weed growth) for four beds/treatment. Herbicide treatments were applied on 4 and 5 Mar., 15 May, 2 July and 30 Sept. in 1992 and 6 Feb., 27 May and 23 Aug. 1993.


A
Control
Low
Mod.
High
Weed intensity
6
5
4
3
2
1
0
B
Weed intensity
5
4
3
2
1
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

not adversely affected by accumulation of Na, Cl, B or heavy metals. In addition, potential health risks to workers or consumers were extremely small. Trees receiving reclaimed wastewater tended to be more vigorous and produced higher yields than those receiving canal water based on recommended soil water depletion levels. More importantly, fertilizer rates could be lowered significantly without reducing yields when using reclaimed wastewater. Fruit growth and quality from trees receiving reclaimed wastewater varied from year-to-year with no clear trends apparent. However, changes in fruit quality such as increased fruit size and reduced TA were generally favorable with the use of reclaimed wastewater. Increased weed growth from use of reclaimed wastewater is a major concern and may require changes in weed management practices such as the use of herbicides with low solubility. However, increased cost for weed management should be compensated for by reductions in fertilizer use and increased yields.

It is important to realize that the results obtained in this study are applicable to the soil type tested, viz., Wabasso fine sand. Although a hardpan was present at about 60 cm, the upper sandy layer had a very high percolation rate and drained rapidly. In areas of the grove where drainage was impeded due to weed buildup or clogging of drainage pipes, trees became stunted and unproductive. Moreover, irrigation rates should be less than 30.7 $mm \cdot wk^{-1}$ and irrigation frequency should be two to three times/wk. It is important to choose groves that are well-designed without low spots to facilitate maximum

drainage. Under these conditions, reclaimed wastewater has the potential to increase yields while saving on fertilizer and irrigation costs.

CHAPTER IV

RECLAIMED WASTEWATER IRRIGATION OF RESET 'MARSH' GRAPEFRUIT TREES

Introduction

Tree losses due to diseases, pests or poor cultural practices average about 4% year (Ferguson and Taylor, 1993; Muraro, 1988; Muraro and Holcomb, 1993). However, freezes in the 1980s have greatly increased tree losses in some areas of Florida. Replacement of dead, diseased and unproductive trees is an important part of maintaining a highly productive citrus grove. Currently, over 50% of citrus growers in Florida plant resets annually (Taylor et al., 1989). Reset tree management presents a challenge not associated with solid plantings of new citrus trees because resets are usually distributed throughout a mature grove and may be overlooked or difficult to find (Jackson, 1981). Cost of planting and management of resets is typically higher than for solid plantings (Muraro, 1988; Taylor et al., 1989). In addition, reset mortality averages from 4-6% within the first year after planting (Ferguson and Taylor, 1993; Jackson et al., 1986). Some problems associated with reset

management include providing adequate freeze protection, weed, ant, and foot rot control and maintaining adequate irrigation and fertilization levels (Ferguson and Taylor, 1993; Jackson et al., 1986; Taylor et al., 1989)

The use of reclaimed wastewater in mature groves may have some potential benefits in the management of resets. Resets must compete with mature trees for available water and nutrients (Jackson, 1981). Similarly, resets have a limited root system with which to extract available water and nutrients. About 85% of the roots are located in the top 25 cm of soil volume 1-year after planting (Marler and Davies, 1989). Growers predominantly use microsprinkler irrigation for resets (Taylor et al., 1989) and realize a net return 1- to 2-years earlier when using microirrigation for newly planted citrus trees compared with conventional irrigation methods (Smajstrla, 1993).

Frequent applications of reclaimed wastewater may be beneficial in maintaining optimum soil moisture for reset growth and development in an established grove. Young 'Valencia' orange trees irrigated at 45% soil water depletion grew better than those at 55% soil water depletion, but trees irrigated at 30% soil water depletion exhibited poor growth and the soil was continuously wet (Smajstrla et al., 1985). In contrast, Marler and Davies (1990) found that irrigation at 20-45% soil water depletion provided optimum growth for young 'Hamlin' orange trees.

Fertilization of resets is costly because rates must be adjusted to ensure that trees receive the correct amount of material (Jackson, 1981). Currently,

62% of resets are fertilized with standard granular fertilizer (Ferguson and Taylor, 1993). Reclaimed wastewater at high rates can supply from two-thirds to all of the yearly N requirement for mature citrus trees, but supplies ≤ 10% of the yearly N requirement for resets due to their limited root system. Newly planted citrus trees receiving simulated reclaimed wastewater alone exhibited N deficiency (Chapter. V).

The objective of these experiments was to determine the effects of reclaimed wastewater irrigation on growth and development of resets in an established grove.

Materials and Methods

Two experiments were designed to evaluate the growth and development of reset 'Marsh' grapefruit trees at various rates of reclaimed wastewater and canal water on a flatwoods type soil. Plantings were located adjacent to the Indian River County municipal wastewater treatment facility at Vero Beach, Fla. within a grove of 25-year old 'Marsh' grapefruit trees. One hundred containerized 'Marsh' grapefruit trees (*Citrus paradisi* Macf.) on 'Swingle' citrumelo (*C. paradisi* Macf. x *Poncirus trifoliata* [L.] Raf.) rootstock ca. 1 year in the nursery (Becker Citrus Nursery, Ft. Pierce, Fla.) were planted on 21 Nov. 1990 (Expt. 1). In addition, one hundred containerized 'Marsh' grapefruit trees on sour orange (*C. aurantium* L.) rootstock ca. 1.5 years in the nursery (Becker Citrus Nursery, Ft. Pierce, Fla.) were planted on 2 Mar. 1993

(Expt. 2). Treatments were arranged as a completely randomized design consisting of five trees (samples) per bed with five beds (replicates) per treatment. Trees were planted to replace dead or missing trees within a mature grove on double beds (18.3 m wide x 177 m length) with trees spaced 9.15 m between rows and 7.6 m within the row. Trees were wrapped with R-11 fiberglass tree wraps for freeze protection and to prevent sprouting and herbicide damage. The soil type was predominantly a Wabasso fine sand (sandy, siliceous, hyperthermic Alfic Haplaquods) with some areas of the grove consisting of Pineda fine sand (loamy, siliceous, hyperthermic Arenic Glossaqualfs) and Riviera fine sand (loamy, siliceous, hyperthermic Arenic Glossaqualfs). The soil had a volumetric field capacity of 9.95% and a permanent wilting point of 2.48% and a mean bulk density of 1.61 $g \cdot cm^{-3}$.

Treatments in 1991 and 92 consisted of a control (canal water) irrigated based on soil water depletion of one-third from Jan.-June and two-thirds from July-Dec. as currently recommended for mature citrus trees (Koo, 1963). However, in 1993 irrigation was applied at one-third soil water depletion the entire year as recommended for young trees (Marler and Davies, 1990). Reclaimed wastewater was applied at low (19.0), moderate (25.4) and high (31.7 $mm \cdot wk^{-1}$) rates (Tables 4.1-3). Trees receiving the low and moderate-reclaimed wastewater treatments were irrigated 2 days/wk and the high-reclaimed wastewater treatment 3 days/wk. Reclaimed wastewater was applied on either a 4- or 5-day/wk schedule during each year, although trees were

Table 4.1. Total water applied via irrigation to 'Marsh' grapefruit trees at Vero Beach, Fla., 1990-91.[z]

Treatments[y]	Oct.-Dec.	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.[y]	Total
			(kl)			
Control						
Canal water	281	313	533	0	1695	2822
Reclaimed wastewater						
Low - 19.0 mm·wk^{-1}	2041	2195	1952	1899	1643	9730
Mod. - 25.4 mm·wk^{-1}	2357	2784	2407	2566	2193	12307
High - 31.7 mm·wk^{-1}	3095	3444	3079	2901	2724	15243

[z] Water was applied to a 0.086 ha area within each tree row for each treatment.
[y] Irrigation was discontinued from 25 Nov. to 16 Dec., 1991 to repair double beds and clean furrows.

Table 4.2. Total water applied via irrigation to 'Marsh' grapefruit trees at Vero Beach, Fla., 1992.[z]

Treatments	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(kl)		
Control					
Canal water	746	2027	0	320	3092
Reclaimed wastewater					
Low - 19.0 mm·wk^{-1}	1920	2141	2100	1694	7855
Mod. - 25.4 mm·wk^{-1}	2450	2845	3281	2295	10870
High - 31.7 mm·wk^{-1}	3066	3566	4040	3060	13732

[z] Water was applied to a 0.086 ha area within each tree row for each treatment.

Table 4.3. Total water applied via irrigation to 'Marsh' grapefruit trees at Vero Beach, Fla., 1993.[z]

Treatments	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(kl)		
Control					
Canal water	470	1616	1693	1226	5004
Reclaimed wastewater					
Low - 19.0 mm·wk^{-1}	1802	2241	2012	1612	7667
Mod. - 25.4 mm·wk^{-1}	2417	2946	2732	2154	10249
High - 31.7 mm·wk^{-1}	2897	3656	3407	2686	12645

[z] Water was applied to a 0.086 ha area within each tree row for each treatment.

irrigated two or three times/wk (Table 4.4). In Dec. 1991 irrigations were suspended to clean water furrows and repair the beds. Trees were irrigated with 56.8 liters/h 360° Maxijet® mircosprinklers.

Trees in Expt. 1 received 0.23, 0.34 and 0.45 kg N/tree per yr in 1991, 92 and 93, respectively, which was applied in five to six equal applications per year within the tree drip-line as currently recommended (Ferguson and Davies, 1989; Koo et al., 1984). Trees in Expt. 2 received 0.23 kg N/tree per yr in 1993. Trees in both experiments received granular fertilizer formulated as a 8N(4%-NH_4^+, 4% NO_3^-)-2P-8K-2Mg (Seminole Marico Brand Fertilizer, Ocala, Fla.).

Tree vigor was rated visually at the end of each year from 1 (poorly growing, unhealthy) to 5 (vigorous, healthy) in 1991 and from 1 to 10 in 1992 and 93 using the same but expanded system to compensate for differences in tree size. Tree height and trunk diameter were measured at planting and at the end of each season. Trunk diameter was measured at a height of 30 cm above ground level.

Leaf tissue samples were taken in Aug. or Sept. from fully expanded spring flush leaves by collecting four leaves from each tree per bed (20 leaves per sample per bed from each of five beds/treatment). Leaves were then processed as described previously (Chapter III, p. 44).

Soil moisture content was monitored with a Troxler 4300 neutron probe (Troxler, Raleigh, N.C.) once a week for the reclaimed wastewater treatments and twice a week for the control treatment. One aluminum access tube was

Table 4.4. Four and five day schedules and amounts of reclaimed wastewater irrigation for 'Marsh' grapefruit trees, Vero Beach, Fla., 1990-93.[z]

Five day irrigation schedule.					
Treatments	Mon.	Tue.	Wed.	Thur.	Fri.
			(mm/day)		
Low - 19.0 mm·wk^{-1}	6.3			12.7	
Mod. - 25.4 mm·wk^{-1}		12.7			12.7
High - 31.7 mm·wk^{-1}	12.7		12.7		6.3
Four day irrigation schedule.					
Treatments	Mon.	Tue.	Wed.	Thur.	Fri.
			(mm/day)		
Low - 19.0 mm·wk^{-1}			19.0		
Mod. - 25.4 mm·wk^{-1}		19.0		6.4	
High - 31.7 mm·wk^{-1}	19.0			12.7	

[z] Amount of reclaimed wastewater applied to 'Marsh' grapefruit trees.

placed at the drip-line of a mature tree within the tree row in about the middle of each bed. Neutron probe readings were taken within the drip-line of mature citrus trees to determine soil moisture content and schedule irrigations. Neutron probe readings were taken at a depth of 23 cm to avoid reading soil moisture levels of the water table.

Water quality was monitored monthly for both the canal water and reclaimed wastewater treatments (Table 3.5) as described previously (Chapter III, p. 46).

Weed intensity ratings were made subjectively for each bed within the tree row and ranged from 0 (no weeds) to 5 (> 50% weed cover). An area around each reset was maintained weed free to prevent competition and obstruction of microsprinkler irrigation. All beds had between row bahiagrass ground cover which was mowed as necessary. In addition, pest, weed and disease control was applied as currently recommended for groves receiving standard irrigation. No adjustments in herbicide or pest control practices were made for the reclaimed wastewater treatments.

Experiments were analyzed as a completely randomized design. The SAS general linear model (GLM) procedure was used to perform analysis of variance. Analysis of covariance was used for tree height and trunk diameter measurements. Orthogonal contrasts were used to determine trends in the data and to separate means.

Results and Discussion

Tree growth and development

Visual ratings of tree vigor, tree height and trunk diameter measurements were similar for all trees in 1991, 92 and 93 for Expt. 1 (Tables 4.5-7). Likewise, trunk diameter measurements were similar for all trees in 1993 for Expt. 2 (Table 4.8). However, tree height for trees receiving the low rates of reclaimed wastewater were significantly smaller than trees receiving the high rates of reclaimed wastewater. In 1991 high levels of melanose on the leaves and poor weed control in Expt. 1 damaged many of the young trees and caused significant differences in tree size and vigor to occur. The coefficient of variability ranged from 15 to 23. For Expt. 2, citrus leaf miners severely reduced tree canopy size and growth of the summer flush which could partially account for the lack of differences related to treatments. Nevertheless, similarities in tree size could also have occurred because the control trees were irrigated at optimum levels (Marler and Davies, 1990). Superoptimum irrigation levels for the reclaimed wastewater treatments therefore should not increase size. Similarly, no differences in tree growth were found for young citrus trees irrigated at 20% soil water depletion and at 19 and 25 $mm \cdot wk^{-1}$ with simulated reclaimed wastewater (Chapter V). In contrast, young citrus trees on the Ridge irrigated with reclaimed wastewater were significantly larger than trees receiving well water (Koo and Zekri, 1989; Parsons and Wheaton, 1992; Wheaton and Parsons, 1993). However, the difference in young tree

Table 4.5. Reclaimed wastewater and canal water effects on vegetative growth and development of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1991-93.[z]

Treatments	Visual rating		
	5 Sept. 91[x]	15 Sept. 92[y]	2 Dec. 93[y]
Control			
Canal water	1.9	6.2	5.8
Reclaimed wastewater			
Low - 19.0 mm·wk^{-1}	2.2	6.5	6.4
Mod. - 25.4 mm·wk^{-1}	1.8	6.3	6.4
High - 31.7 mm·wk^{-1}	1.7	6.5	6.3
Significance			
Treatment	NS	NS	NS

[z] Each number represents the mean of five trees/bed and five beds/treatment.
[x] Visual ratings ranged from 1 (a poorly growing, unhealthy) to 5 (a healthy, vigorous) tree.
[y] Visual ratings ranged from 1 (a poorly growing, unhealthy) to 10 (a healthy, vigorous) tree.
[NS] Nonsignificant.

Table 4.6. Reclaimed wastewater and canal water effects on tree height of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1990-93.[z]

Treatments	Tree ht (cm)			
	21 Nov. 90	5 Sept. 91	15 Sept. 92	2 Dec. 93
Control				
Canal water	53.0[y] (51.9)	94.7 (94.0)	143.5 (142.4)	245.9 (245.7)
Reclaimed wastewater				
Low - 19.0 mm·wk^{-1}	53.0 (52.4)	90.4 (90.1)	148.8 (148.0)	237.9 (237.8)
Mod. - 25.4 mm·wk^{-1}	53.0 (54.3)	91.0 (91.8)	149.8 (151.5)	244.2 (244.6)
High - 31.7 mm·wk^{-1}	53.0 (53.5)	85.9 (86.2)	157.0 (157.5)	255.1 (255.2)
Significance				
Treatment	NS	NS	NS	NS

[z] Each number represents the mean of five trees/bed and five beds/treatment.
[y] Numbers in parenthesis are actual means. Other numbers represent adjusted means from the analysis of covariance.
[NS] Nonsignificant.

Table 4.7. Reclaimed wastewater and canal water effects on trunk diameter of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1990-93.[z]

Treatments	Trunk diam (mm)[y]			
	21 Nov. 90	5 Sept. 91	15 Sept. 92	2 Dec. 93
Control				
Canal water	4.9[x] (4.8)	15.3 (15.3)	36.4 (36.3)	70.0 (69.9)
Reclaimed wastewater				
Low - 19.0 mm·wk^{-1}	4.9 (4.9)	14.6 (14.6)	35.4 (35.4)	67.3 (67.2)
Mod. - 25.4 mm·wk^{-1}	4.9 (4.8)	14.9 (14.8)	33.8 (33.8)	67.5 (67.3)
High - 31.7 mm·wk^{-1}	4.9 (5.1)	13.9 (14.0)	34.5 (34.6)	67.2 (67.6)
Significance				
Treatment	NS	NS	NS	NS

[z] Each number represents the mean of five trees/bed and five beds/treatment.
[y] Trunk diameter measurements were taken approximately 20 cm above ground level.
[x] Numbers in parenthesis are actual means. Other numbers represent adjusted means from the analysis of covariance.
[NS] Nonsignificant.

Table 4.8. Reclaimed wastewater and canal water effects on trunk diameter and tree height of reset 'Marsh' grapefruit trees planted June 1993 at Vero Beach, Fla., 1993.[z]

Treatments	Trunk diam (mm)[y]		Tree ht (cm)	
	2 Mar. 93	2 Dec. 93	2 Mar. 93	2 Dec. 93
Control				
Canal water	8.2	17.0	58.1	93.8
Reclaimed wastewater				
Low - 19.0 mm·wk^{-1}	8.0	16.4	56.7	88.3
Mod. - 25.4 mm·wk^{-1}	8.7	16.3	58.2	97.5
High - 31.7 mm·wk^{-1}	8.3	18.1	58.0	103.1
Significance				
Treatment	NS	NS	NS	*
Contrasts[x]				
Low vs. High				**

[z] Number represents the mean of five trees/bed and five beds/treatment.
[y] Trunk diameter measurements were taken approximately 20 cm above ground level.
[x] Only significant contrasts are presented.
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

growth may have resulted from less than optimum irrigation for trees receiving well water. Although mature citrus trees receiving reclaimed wastewater increased in size and yield compared to well or canal water irrigated trees (Chapter III; Zekri and Koo, 1993), the canal and well water trees received irrigation at the recommended soil water depletion levels which are below levels for maximum tree growth and yield for mature citrus trees (Koo, 1963).

Leaf tissue analysis

Leaf tissue N concentrations were similar and in the high range (2.8-3.0%) (Koo et al., 1984) for all trees in 1991 (Table 4.9). In 1992, leaf N was significantly higher for trees receiving canal water than the reclaimed wastewater trees. However, all leaf N levels were within the optimum range (2.5-2.7%) (Koo et al., 1984) (Table 4.10). Similarly, in 1993 leaves from trees in the low and high reclaimed wastewater treatments had significantly lower N than those of the canal water trees, but levels were still within the optimum range (Table 4.11). The high levels of N found in leaf tissue are similar to those found for young 'Hamlin' orange trees in Florida (Obreza and Rouse, 1993; Willis et al., 1991) and 'Ray Ruby' grapefruit trees in Texas (Swietlik, 1992). Leaf N levels are quite variable and are often higher for leaves from young non-bearing trees compared to those of mature trees.

Leaf K was significantly higher for trees receiving reclaimed wastewater treatments (1.7-1.9%) (Koo et al., 1984) compared to those receiving canal

Table 4.9. Reclaimed wastewater and canal water effects on leaf tissue concentrations of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1991.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	2.9	0.20	1.5	2.9	0.51	226	55	53	48	12	22
Reclaimed wastewater											
Low - 19.0 $mm \cdot wk^{-1}$	3.0	0.23	1.7	2.4	0.48	986	79	30	47	11	23
Mod. - 25.4 $mm \cdot wk^{-1}$	3.0	0.19	1.8	2.4	0.48	1060	78	43	51	10	22
High - 31.7 $mm \cdot wk^{-1}$	3.0	0.21	1.9	2.4	0.48	1096	78	26	40	7	21
Significance											
Treatment	NS	NS	**	**	NS	***	***	NS	NS	*	NS
Contrasts[x]											
CW vs. Low			*	**		***	***				
CW vs. Mod.			**	**		***	***				
CW vs. High			***	**		***	***			**	
Low vs. High										**	

[z] Each number represents the mean of five leaves/tree from four trees/bed and five beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1991.
[y] Trees received fungicide sprays which contained Cu.
[x] Only significant contrasts are presented.
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 4.10. Reclaimed wastewater and canal water effects on leaf tissue concentrations of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1992.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	3.0	0.20	0.9	5.2	0.45	886	130	743	233	18	28
Reclaimed wastewater											
Low - 19.0 $mm \cdot wk^{-1}$	2.8	0.18	1.0	5.0	0.49	884	109	904	259	20	30
Mod. - 25.4 $mm \cdot wk^{-1}$	2.8	0.24	0.9	5.2	0.46	956	110	1109	228	20	29
High - 31.7 $mm \cdot wk^{-1}$	2.7	0.19	1.1	5.0	0.46	934	121	1253	294	19	31
Significance											
Treatment	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts[x]											
CW vs. Low	*										
CW vs. Mod.	*										
CW vs. High	**										

[z] Each number represents the mean of five leaves/tree from four trees/bed and five beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1992.
[y] Trees received fungicide sprays which contained Cu.
[x] Only significant contrasts are presented.
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 4.11. Reclaimed wastewater and canal water effects on leaf tissue concentrations of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1993.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	3.0	0.14	1.7	3.4	0.39	1056	89	220	42	14	22
Reclaimed wastewater											
Low - 19.0 $mm \cdot wk^{-1}$	2.7	0.14	1.9	3.4	0.39	1274	177	235	44	14	23
Mod. - 25.4 $mm \cdot wk^{-1}$	2.9	0.15	2.0	3.2	0.38	1206	181	251	48	13	24
High - 31.7 $mm \cdot wk^{-1}$	2.6	0.14	2.0	3.4	0.37	1254	182	241	44	9	24
Significance											
Treatment	*	NS	**	NS	NS	NS	***	NS	NS	NS	NS
Contrasts[x]											
CW vs. Low	*		*				***				
CW vs. Mod.			**				***				
CW vs. High	**		***				***				
Mod. vs. High	*										

[z] Each number represents the mean of five leaves/tree from four trees/bed and five beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Sept. 1993.
[y] Trees received fungicide sprays which contained Cu.
[x] Only significant contrasts are presented.
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

water in 1991 (Table 4.9). Conversely, in 1992 all trees had similar leaf K concentrations, but levels were in the low range (0.9-1.1%) (Koo et al., 1984) (Table 4.10). In 1993, trees receiving the reclaimed wastewater treatments again had significantly higher leaf K (1.9-2.0%) compared to those receiving canal water (1.7%) (Table 4.11). The increase in leaf K for trees receiving reclaimed wastewater probably occurred because of high K levels in the reclaimed wastewater. Although mature trees receiving reclaimed wastewater had similar leaf K levels for 2 of 3 years (Chapter III), fertilization was adjusted so that all trees received about the same level of K. In contrast, resets in this experiment all received granular fertilizer plus additional K in the reclaimed wastewater which had twice the concentration of K as well water and could account for the higher leaf K levels for resets receiving reclaimed wastewater.

Leaf Ca was significantly higher for trees receiving canal water than those receiving reclaimed wastewater treatments in 1991 (Table 4.9), with all leaves in the low range (1.5-2.9%) (Koo et al., 1984). Leaf Ca concentration was similar and in the high range for all trees in 1992 (5.0-6.9%) (Koo et al., 1984) (Table 4.10). In 1993 leaf Ca levels were similar for all trees and in the optimum range (3.0-4.9%) (Koo et al., 1984) (Table 4.11). Although the reclaimed wastewater trees received larger volumes of water than the canal water trees, the canal water had about three times the level of Ca, thus accounting for no differences in leaf Ca levels (Table 3.5, p. 47).

There was concern that relatively high levels of Na and B in the reclaimed wastewater would adversely affect growth and development of young trees. Leaf Na concentrations were significantly higher in 1991 for trees receiving reclaimed wastewater than those receiving canal water (Table 4.9) The increase in leaf Na for the reclaimed wastewater trees is likely due to the high volume of water applied since Na levels in both water sources were similar (Table 3.5, p. 47). However, in 1992 and 93 leaf Na concentrations were similar for all trees (Tables 4.10-11). Leaf Na concentrations for all 3 years were below toxic levels of > 2500 $\mu g \cdot g^{-1}$ (Smith and Reuther, 1954) and thus were not of concern.

Reclaimed wastewater treated trees had significantly higher leaf B levels than trees receiving canal water in 1991 (Table 4.9). However, all levels were within the optimum range (36-100 $\mu g \cdot g^{-1}$) (Koo et al., 1984). In 1992, all trees had similar leaf B concentrations which were in the high range (101-200 $\mu g \cdot g^{-1}$) (Koo et al., 1984) (Table 4.10). In 1993, again trees receiving reclaimed wastewater had leaf B concentrations significantly higher (high range) than the canal water trees (optimum range) (Table 4.11). The increase in leaf B for trees receiving the reclaimed wastewater treatment is attributed to the high volume of water applied and to the high levels of B in the reclaimed wastewater. Similar results have been observed for young (Chapter V; Wheaton and Parson, 1993) and mature citrus trees (Chapter III; Zekri and Koo, 1993) irrigated with reclaimed wastewater in the Conserv II project.

Leaf P, Mg, Cu, Fe, Mn and Zn concentrations were similar for all trees in all 3 years (Tables 4.9-11). Leaf P was in the high range (0.17-0.29%) (Koo et al., 1984) in 1991 and 92, and decreased to the optimum range (0.12-0.16%) (Koo et al., 1984) in 1993. Similarly, young citrus trees receiving simulated reclaimed wastewater had high leaf P levels in the first 2 years, but levels decreased to the optimum range in the third year (Chapter V, Expt. 1). All trees had similar leaf Mg concentrations for all 3 years. Although the canal water had twice the level of Mg as the reclaimed wastewater, all trees received the same level of Mg from granular fertilization. Leaf Cu and Fe concentrations varied from year-to-year and were extremely high in 1992. However, these high levels resulted from yearly Cu sprays for melanose control. Leaf Mn and Zn concentrations were not significantly different due to their low levels in both water sources.

In Expt. 2, which represents only a single year's data, all trees had similar leaf N concentrations which were in the excess range from mature trees, but were typical of young trees (≥ 3.0%) (Koo et al., 1984) (Table 4.12). Leaf nutrient concentrations were also similar for P, K, Mg, Cu, Fe, Mn and Zn (Table 4.12). However, leaf Ca levels for trees receiving canal water were again significantly higher than those receiving reclaimed wastewater. Which could be attributed to the canal water having three times the Ca concentration as the reclaimed wastewater. Leaf Na was also significantly higher for trees receiving the low-reclaimed wastewater treatment compared to other treatments. All trees

Table 4.12. Reclaimed wastewater and canal water effects on leaf tissue concentrations of reset 'Marsh' grapefruit trees planted June 1993 at Vero Beach, Fla., 1993.[z]

Treatments	N	P	K	Ca	Mg	Na	B	Cu[y]	Fe	Mn	Zn
	(% dry wt)					($\mu g \cdot g^{-1}$ dry wt)					
Control											
Canal water	3.0	0.15	1.9	2.6	0.51	2702	66	558	60	24	26
Reclaimed wastewater											
Low - 19.0 $mm \cdot wk^{-1}$	3.2	0.17	2.1	2.1	0.49	4946	151	884	76	23	30
Mod. - 25.4 $mm \cdot wk^{-1}$	3.2	0.17	2.3	2.1	0.48	3612	155	652	60	20	24
High - 31.7 $mm \cdot wk^{-1}$	3.1	0.16	2.2	2.2	0.49	4114	184	858	59	16	25
Significance											
Treatment	NS	NS	NS	*	NS	*	***	NS	NS	NS	NS
Contrasts[x]											
CW vs. Low				**		**	***				
CW vs. Mod.				**			***				
CW vs. High				*			***				
Low vs. High							*				
Mod. vs. High							*				

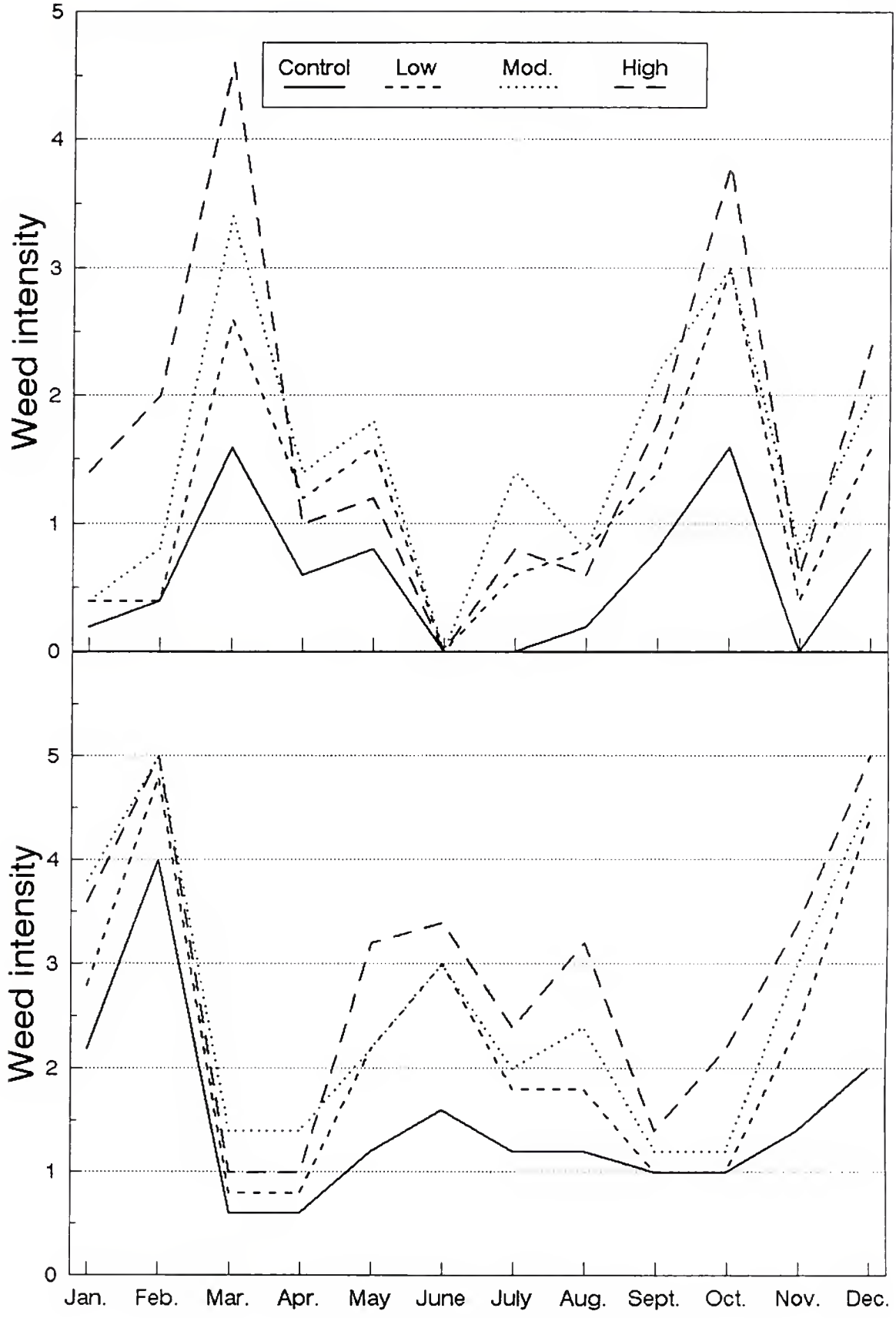
[z] Each number represents the mean of five leaves/tree from four trees/bed and five beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Sept. 1993.
[y] Trees received fungicide sprays which contained Cu.
[x] Only significant contrasts are presented.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

had leaf Na levels > 2500 $\mu g \cdot g^{-1}$ (excess), however, no toxicity symptoms were observed. Leaf Na levels in the first year of growth are substantially higher in Expt. 2 compared to Expt. 1. Although trees on sour orange rootstock are more salinity tolerant than trees on 'Swingle' citrumelo rootstock (Castle, 1987), trees on sour orange rootstock are considered Na accumulators and those on 'Swingle' citrumelo Na excluders (Zekri and Parsons, 1992). The difference in rootstocks between Expt. 1 and 2 may account for the higher leaf Na levels for trees in Expt. 2, which were on sour orange rootstock. Trees receiving reclaimed wastewater had leaf B concentrations significantly higher than trees receiving canal water. In addition, trees receiving the high-reclaimed wastewater treatment had significantly higher leaf B concentrations than the other reclaimed wastewater treatments. Nevertheless, leaf B concentrations were not in the toxic range. The increase in leaf B can be attributed to the level of reclaimed wastewater used which contained about four times more B than the canal water. Similar increases in leaf B from the use of reclaimed wastewater were observed in Expt. 1 and for mature (Chapter III; Zekri and Koo, 1993) and young citrus trees (Chapter V)

Weed growth

Weed intensity was greater in beds receiving the reclaimed wastewater treatments than for those receiving the canal water in 1992 and 93 (Fig. 4.1A and B, respectively). Weed growth varied seasonally in 1992 and 93. Winter

Fig. 4.1. Reclaimed wastewater and canal water effects on weed growth in the tree row for 'Marsh' grapefruit at Vero Beach, Fla., 1992 (A) and 93 (B). Control = canal water, and reclaimed wastewater at low = 19.0 mm·wk^{-1}, mod. = 25.4 mm·wk^{-1} and high 31.7 mm·wk^{-1}. Rating was based on a scale of 0 (no weed growth) to 5 (>50% weed growth) for five beds/treatment. Herbicide treatments were applied on 4, 5 Mar., 15 May, 2 July and 30 Sept. 1992 and 6 Feb., 27 May and 23 Aug. 1993.


Control
Low
Mod.
High
Weed intensity
Weed intensity
0
1
2
3
4
5
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

annuals were prevalent in Jan. and Feb. but decreased following herbicide treatments in March. In May 1992 a second herbicide treatment was applied. Weed levels again increased from June-Sept. Following application of glyphosate on 30 Sept. weed levels decreased, but winter annuals again increased until February when weeds were herbicided. Weed growth increased from Mar.-May and June-Aug. until beds were herbicided on 27 May and 23 Aug., respectively. Weed growth again increased from Oct. until Jan. Weed pressure was greatest for beds receiving reclaimed wastewater. In addition, weed growth tended to increase with increased reclaimed wastewater application.

Increases in growth of annual and perennial weeds is a potential drawback to the use of high rates of reclaimed wastewater particularly for young trees. Similar increases in weed growth have been reported from the use of reclaimed wastewater for irrigation of citrus trees (Chapter III; Wheaton and Parsons, 1993; Zekri and Koo, 1993). Changes in weed management practices may be required when using high rates of reclaimed wastewater. Using less water soluble herbicides or increasing herbicide frequency could significantly increase weed management costs.

Reclaimed wastewater irrigation of resets under mature tree management systems was used with no detrimental effects on tree growth. In this experiment there were no apparent increases in tree growth from the use of reclaimed wastewater as previously observed for young citrus trees (Chapter

III; Koo and Zekri, 1989; Wheaton and Parsons, 1993). Irrigation was adequate for growth and development of resets within a mature grove as all trees had optimum soil moisture levels. Likewise, tree vigor was similar regardless of irrigation above optimum levels (Chapter V). However, resets should be fertilized on a regular young tree program because insufficient nutrients are available in the reclaimed wastewater to support growth (Chapter III), but fertilizer levels may be reduced to account for nutrients in the reclaimed wastewater as the trees mature. Leaf Na and B levels were increased from the use of reclaimed wastewater, but below phytotoxic levels. Weed pressures from the use of reclaimed wastewater increased and may require changes in herbicide programs and increase production costs.

CHAPTER V

USE OF RECLAIMED WASTEWATER FOR IRRIGATION AND FERTIGATION OF YOUNG 'REDBLUSH' GRAPEFRUIT TREES

Introduction

In Florida, 41% of all water is used for agricultural purposes (Fernald and Patton, 1984) with 34% of this water used to irrigate citrus (Smajstrla et al., 1992). Due to the increasing demand for water, water use for agricultural purposes has become strictly regulated by Florida's water management districts. Additionally, urban growth, especially in the coastal areas, has increased the need for efficient and environmentally safe deposal of reclaimed wastewater. The Department of Environmental Protection (DEP) has restricted the disposal of municipal reclaimed wastewater into lakes, rivers and streams, so alternative disposal sites need to be found.

The restrictions on water use for agriculture and the need for alternative disposal sites for municipal reclaimed wastewater are concerns that may be partially alleviated by the use of reclaimed wastewater for citrus irrigation. Reclaimed wastewater has been successfully used to irrigated apples (Nielsen

et al., 1989a), cherries (Neilsen et al., 1991), grapes (Nielsen et al., 1989b), peaches (Basiouny, 1984) and citrus (Kale and Bal, 1987; Koo and Zekri, 1989; Omran et al., 1988; Wheaton and Parsons, 1993; Zekri and Koo, 1990; Zekri and Koo, 1993). Reclaimed wastewater as an alternative water source for the irrigation of citrus trees has many potential advantages. Reclaimed wastewater contains many nutrients essential for plant growth, and may have an effect similar to that of frequent fertigation with a dilute concentration of plant nutrients (Neilsen et al., 1989a). In addition, recycling these nutrients may prevent pollution of surface or ground water (Sanderson, 1986). The primary concern with the use of reclaimed wastewater is the potential accumulation of phytotoxic levels of heavy metals (Omran et al., 1988). Salinity of reclaimed wastewater is normally within acceptable ranges and often lower than other irrigation waters; however, levels may be acceptable only for under tree use (Basiouny, 1982).

Long term studies using reclaimed wastewater to irrigate citrus for up to 60 years in Egypt found no adverse effects on tree growth as compared to well water (Omran et al., 1988). Similarly, irrigation with reclaimed wastewater increased growth and yield of citrus on the Ridge area of Florida with no adverse affects (Koo and Zekri, 1989; Zekri and Koo, 1990; Zekri and Koo, 1993). Similar results were observed for young citrus trees (Wheaton and Parsons, 1993; Zekri and Koo, 1990). However, these studies were conducted on citrus trees growing on the well-drained soils of the Ridge. Soils types and

drainage patterns of the flatwoods vary considerably from those of the Ridge due to the presence of hardpans and high water tables. The potential waterlogging of the flatwoods presents problems not associated with citrus grown on the Ridge. In addition, no studies have been conducted on newly planted, nonbearing citrus trees irrigated with reclaimed wastewater.

The objective of these experiments was to evaluate the effects of reclaimed wastewater on the growth and development of citrus trees during the first 3 years after planting on both well-drained and poorly drained soils.

Materials and Methods

Reclaimed wastewater and well water irrigation on Arredondo fine sand (Expt. 1)

Bare-rooted 'Redblush' grapefruit trees on 'Swingle' citrumelo rootstock (≈ 2 years in the nursery) were obtained from A. Duda and Sons Citrus Nursery (LaBelle, Fla.) and planted on 21 April, 1990. Trees were planted at the University of Florida Fifield farm in Gainesville, Fla. and grown for three years. Soil type was Arredondo fine sand (Loamy, siliceous, hyperthermic, Grossarenic, Paludults) with a volumetric field capacity of 10.2%, a permanent wilting point of 1.7% and 1.66 $g \cdot cm^{-3}$ mean bulk density. Trees were planted in single rows spaced 4.6 m within rows and 6.1 m between rows.

Trees were irrigated for 3 weeks after planting for about 2 h every other day using 37.8 liter/h 90° Maxijet® microsprinklers located 1 m northwest of

the tree trunk in 1990 and 91. In 1992 emitters were changed to 37.8 liter/h 180° microsprinklers located 1 m west of the tree trunk (Marler and Davies, 1989). Trees were wrapped with R-11 fiberglass tree wraps (Adaco, Inc. Clermont, Fla.) to provide freeze protection and reduce sprouting.

Treatments were arranged as a 3 (water sources) x 3 (irrigation levels) factorial experiment with 10 single tree replicates per treatment based on previous studies (Marler and Davies, 1990). Treatments included reclaimed wastewater (RCW), reclaimed wastewater plus fertigation (RCW+F) and well-water plus fertigation (WW+F). The simulated reclaimed wastewater (nutrient solution) was formulated based on a typical elemental water analysis from the Indian River County municipal wastewater treatment facility at Vero Beach, Fla. (Table 5.1). The composition of the simulated reclaimed wastewater was changed after 1990 to more accurately simulate that of the treatment facility. Water samples were collected and analyzed by the Analytical Research Laboratory, University of Florida, Gainesville, Fla.

Fertigation was applied every 3 weeks (10 times in 1990 and 11 times in 1991 and 92). In-line 2% fixed Dosatron injectors (Dosatron International, Clearwater, Fla.) were used to apply liquid fertilizer and the simulated reclaimed wastewater. The liquid formulation analysis was (8N [4.0% NH_4^+, 4.0% NO_3^-]-0P-8K) as ammonium nitrate and potassium chloride (Stauffer Chemical, Leesburg, Fla. in 1990 and 91 and Chemical Dynamics, Plant City, Fla. in 1992). Injectors were also used to apply the simulated reclaimed

Table 5.1. Nutrient concentration and pH of well-water and simulated reclaimed wastewater at Fifield (Arredondo fine sand)(Ridge) and Horticultural Unit research farms (Kanapaha fine sand)(flatwoods), 1990-92.

pH	EC	NH_4^+-N	NO_3^--N	P	K	Ca	Mg	Na	Cl	Cu	Fe	Mn	Zn	B
							(mg·liter^{-1})							
Well water														
Expt. 1[z]														
7.7	0.35	0.0	5.7	0.2	0.9	47.2	2.7	4.4	8.3	0.0	0.01	0.0	0.05	0.02
Expts. 2, 3 &4[y]														
7.5	0.45	0.0	0.8	0.2	0.6	59.9	14.0	6.6	7.3	0.0	0.01	0.0	0.04	0.05
Simulated reclaimed wastewater[x]														
Expts. 1 & 2 1990														
—[w]	—[w]	3.0	4.3	4.9	35.9	59.0	28.8	119	200	—[w]	—[w]	—[w]	0.06	0.26
Expt. 1 1991-92														
7.5	1.80	4.5	10.5	7.8	21.1	45.8	27.4	280	387	0.0	0.01	0.01	0.10	0.81
Expts. 2, 3 & 4 1991-92														
7.4	1.95	3.7	5.0	7.4	20.5	56.7	36.9	273	393	0.0	0.06	0.01	0.08	0.84

[z] Expt. 1 was conducted on the Arredondo fine sand (Ridge).
[y] Expts. 2, 3 and 4 were conducted on Kanapaha sand (flatwoods).
[x] Composition of the simulated reclaimed wastewater was modified after 1990 to reflect levels obtained in the Indian River county municipal wastewater treatment facility at Vero Beach, Fla.
[w] Missing data.

wastewater with each irrigation. Irrigation was applied to all treatments during fertigation so that each tree received 30 liters/water. Total N/tree per yr for the RCW, RCW+F and WW+F treatments was < 23, 230 and 230 g, respectively, in 1990; < 34, 340 and 340 g, respectively, in 1991; and < 46, 460, and 460 g, respectively in 1992. Rates of 230, 340, and 460 g N/tree per yr are currently within recommended ranges in Florida for 1-, 2- and 3-year old citrus trees, respectively (Ferguson and Davies, 1989; Koo et al., 1984).

Irrigation was applied when the soil reached 20% soil water depletion (SWD) as determined previously (Marler and Davies, 1990), or at 19 and 25 $mm \cdot wk^{-1}$ which simulates frequent irrigations associated with reclaimed wastewater application. Trees received irrigation for 31, 39 and 37 weeks in 1990, 91 and 92, respectively. Total liters of water/tree per yr for the three treatments were 472, 1619 and 2746 in 1990; 731, 2037 and 3454 in 1991; and 2063, 3759 and 6378 in 1992. The 19 and 25 $mm \cdot wk^{-1}$ treatments were irrigated three times/wk regardless of rainfall with a 1 day minimum between irrigations.

Soil moisture levels were monitored with a Troxler 4300 neutron probe (Troxler, Raleigh, N.C.). Soil moisture was determined 3 times/wk just prior to irrigation. Four aluminum access tubes were placed 30 cm north of the trunks of four trees in each of the three irrigation levels in 1990, 91 and 92. Neutron probe readings were taken at a depth of 30 cm since 85% of young citrus tree

roots are located from 15 to 46 cm below the soil surface (Marler and Davies, 1990).

Between-row bahiagrass ground cover was mowed as needed and 1.8 m within the tree rows was maintained weed free with herbicides. Pesticides were applied when necessary.

Reclaimed wastewater and well water irrigation on Kanapaha fine sand (Expt. 2.)

Bare-rooted 'Redblush' grapefruit trees on 'Swingle' citrumelo rootstock (≈ 2 years in the nursery) were obtained from A. Duda and Sons (LaBelle, Fla.) planted 6 April, 1990 and grown for two seasons. Trees were planted at the University of Florida Horticultural Research Unit near Gainesville, Fla. on double row beds (16.8 m width x 0.6-0.8 m height x 84 m length). Trees were spaced 3.4 m within rows and 7.6 m between rows on each double bed. Soil type was Kanapaha fine sand (loamy, siliceous, hyperthermic, Grossarenic, Paleaquults) with a loamy or clayey layer starting ≈ 1.2 m below the top of the soil surface and a water table fluctuating between 0.4 and 1.5 m from the top of the bed (Marler, 1988). The soil had a volumetric field capacity of 11.3%, a permanent wilting point of 2.0% and 1.56 $g \cdot cm^{-3}$ mean bulk density (Marler and Davies, 1989). Treatments were the same as Expt. 1, except that trees received 473, 1620 and 2744 liters of water/tree per yr in 1990 and 731, 2036 and 3456 liters of water/tree per yr in 1991.

Reclaimed wastewater and well water irrigation comparing liquid vs granular fertilization (Expt. 3)

Bare-rooted 'Redblush' grapefruit trees on a 'Swingle' citrumelo rootstock (≈ 2 years in the nursery) were obtained from Florida Citrus Nursery (Avon Park, Fla.), planted 21 March, 1991 and grown for two seasons at the University of Florida Horticultural Research Unit near Gainesville, Fla. Site characteristics are the same as those for Expt. 2. Treatments were arranged as a 3(water sources) x 3(irrigation levels) factorial experiment with 10 single tree replicates per treatment. Trees were irrigated for two weeks prior to initiating treatments after planting. Treatments included reclaimed wastewater plus granular fertilization (RCW+G), reclaimed wastewater plus fertigation (RCW+F) and well-water plus fertigation (WW+F). Granular fertilizer was applied every 6 weeks within the tree drip-line in 5 equal applications at 230 and 340 g N/tree per yr in 1991 and 92, respectively. Fertilizer analysis was (8N [4.0% NH_4^+, 4.0% NO_3^-]-2P -8K-2Mg) derived from ammonium nitrate, diammonium phosphate, muriate of potash and magnesium sulfate (Seminole Marico Brand Fertilizer, Ocala, Fla.). Trees received 230 and 340 g N/tree per yr in 1991 and 92, respectively. Irrigation was applied at 20% soil water depletion (SWD), 19 or 25 $mm \cdot wk^{-1}$ for 39 and 37 weeks in 1991 and 92, respectively. Trees received 731, 2036 and 3456 liters of water/tree per yr in 1991 and 1166, 1881 and 3187 liters of water/tree per yr in 1992.

Reclaimed wastewater and well water irrigation comparing liquid vs granular fertilization (Expt. 4)

Bare-rooted 'Redblush' grapefruit trees on 'Swingle' citrumelo rootstock (≈ 2 years in the nursery) were obtained from Florida Citrus Nursery (Avon Park, Fla.) planted 3 April, 1992 at the University of Florida Horticultural Research Unit near Gainesville, Fla. Site characteristics are the same as those for Expts. 2 and 3. Treatments began 4 days after planting. Design and treatments were the same as Expt. 3, except that trees received 988, 1881 and 3187 liters of water/tree per yr in 1992.

Measurements of tree growth, leaf tissue and yield

Tree measurements included visual ratings based on canopy size and vigor at the end of each year and tree height taken at planting and again at the end of each growing season. Ratings ranged from 1 (a poorly growing, unhealthy tree) to 5 (a healthy, vigorous tree) in 1990, 91 and 92. However, for Expt. 1 in 1992 ratings ranged from 1 (a poorly growing, unhealthy tree) to 10 (a healthy, vigorous tree). Visual evaluations of new leaf flushes were taken weekly during the season to determine timing and number of flushes. Trunk diameters were measured about 30 cm above ground level after planting and after each growth flush. Successive leaf samples were taken at the end of each mature flush when leaves were fully expanded (≈ 3 months old) and a final analysis in December on the final leaf flush in 1990 and 91. In 1992, leaf

samples were collected in August from mature fully expanded spring flush leaves (≈ 5 months old) as recommended (Koo et al., 1984). A 10-leaf sample was collected from two trees (one replicate) and repeated four times for each treatment. Leaves were then processed as previously described (Chap. III, p. 44).

Fruit yield and quality data were taken in December 1992 only for Expt. 1. Fruit were harvested from each tree and processed on a roller type sizer (Food Machinery Corporation, Lakeland, Fla.). Fruit were then counted and weighed in each size category. Fruit weight, juice weight, peel thickness, total soluble solids (TSS) and titratable acid (TA) were determined on three 10-fruit samples from each treatment. Fruit were sectioned equatorially so that peel thickness could be measured and juice extracted by hand with a Sunkist motor driven extractor. TSS was determined with a temperature compensating refractometer and TA by titration of a 25 ml aliquot of juice with 0.3125N NaOH to a pH of 8.2. (Wardowski et al., 1979)

Statistical analysis

Field studies were analyzed as factorial experiments with three water sources and three irrigation levels arranged in a completely random design. The SAS general linear model (GLM) procedure was used to perform analysis of variance (ANOVA). Trunk diameter and tree height were subject to analysis of covariance to standardize differences in initial plant measurements at

planting. Orthogonal contrasts were used to determine trends in the data and to separate means.

Results and Discussion

Growth and development

Visual ratings of tree growth for Expts. 1 and 2 showed similar trends, with the RCW+F trees having the largest tree canopies (Tables 5.2-3). In addition, mature leaves on the RCW trees showed symptoms of N deficiency and had yellowish-green leaves as compared to the dark-green leaves of the other trees. In 1991, the RCW+F trees had significantly larger canopies than the RCW or WW+F trees for Expts. 1 and 2. For Expt. 1 in 1992, the RCW+F and WW+F trees had significantly larger canopies than the RCW trees. For Expt. 3 in 1991, the RCW+F trees had significantly larger canopies than the RCW+G or WW+F trees (Table 5.4). However, in 1992 all trees had similar visual ratings for Expts. 3 and 4 (Table 5.4).

For Expts. 1 and 2 in 1990 all trees had 3 growth flushes. In contrast, in 1991 the RCW trees had 3 growth flushes for both Expts. 1 and 2, but the RCW+F and WW+F trees had a fourth growth flush (data not shown). All trees had the same number and timing of growth flushes per season for Expts. 3 and 4.

Trees receiving RCW+F had a significantly greater height than either the RCW or WW+F tree for Expt. 1 in 1990, 91 and 92 (Table 5.2). A similar trend

Table 5.2. Visual rating, tree height and trunk diameter measurements of young 'Redblush' grapefruit trees as affected by water source and irrigation level in 1990-92, Expt. 1 (Arredondo sand, Ridge).

Treatments[z]		Arredondo sand (Expt. 1)								
Water source	Irr. level	Visual rating[y]			Tree ht[x] (cm)			Trunk diam[x] (mm)		
		1990	1991	1992	1990	1991	1992	1990	1991	1992
RCW	20% SWD	2.1	2.6	3.5	92	175	227	21.2	41.6	65.6
RCW	19 mm·wk^{-1}	2.4	3.3	4.7	107	207	249	23.0	44.0	67.5
RCW	25 mm·wk^{-1}	2.7	3.2	5.5	105	211	262	24.0	46.4	71.9
RCW+F	20% SWD	2.9	3.7	6.8	111	222	266	25.3	55.0	81.9
RCW+F	19 mm·wk^{-1}	2.9	3.4	6.4	119	214	265	25.4	53.1	78.5
RCW+F	25 mm·wk^{-1}	2.9	3.5	6.5	114	221	269	26.2	54.2	78.7
WW+F	20% SWD	2.5	2.6	6.5	101	184	253	23.3	45.0	70.7
WW+F	19 mm·wk^{-1}	2.8	2.7	5.2	109	193	258	24.8	47.6	74.4
WW+F	25 mm·wk^{-1}	2.7	3.0	6.7	107	205	283	23.1	47.2	77.3
Significance										
Water source		NS	***	***	*	***	**	***	***	***
Irr. level		NS	NS	NS	*	**	**	NS	NS	NS
Water x Irr.		NS	NS	NS	NS	*	NS	NS	NS	NS
Contrasts										
RCW vs RCW+F			**	***	**	***	**	***	***	***
RCW vs WW+F				***			**			**
RCW+F vs WW+F			***		*	***		*	***	**

[z] RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water; SWD = soil water depletion.
[y] Subjective visual ratings ranged from 1 (a poorly growing, unhealthy tree) to 5 (a healthy, vigorous tree) in 1990 and 91 and 1 (a poorly growing, unhealthy tree) to 10 (a healthy, vigorous tree) in 1992.
[x] Data values represent the actual means, although data were statistically analyzed using analysis of covariance.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

Table 5.3. Visual rating, tree height and trunk diameter of young 'Redblush' grapefruit trees 1990-91 as affected by water source and irrigation level, Expt. 2 (Kanapaha sand, flatwoods).

Treatments[z]		Visual rating[y]		Tree ht[x] (cm)		Trunk diam[x] (mm)	
Water source[z]	Irr. level	1990	1991	1990	1991	1990	1991
RCW	20% SWD	2.4	3.0	93	202	22.5	43.3
RCW	19 mm·wk^{-1}	2.3	3.2	96	207	22.2	44.0
RCW	25 mm·wk^{-1}	2.5	3.3	98	214	22.7	43.2
RCW+F	20% SWD	3.0	4.2	116	241	26.1	54.3
RCW+F	19 mm·wk^{-1}	3.3	4.4	121	237	27.0	56.1
RCW+F	25 mm·wk^{-1}	3.0	4.4	120	239	27.4	57.8
WW+F	20% SWD	2.6	3.1	102	212	23.7	46.5
WW+F	19 mm·wk^{-1}	2.6	3.7	111	224	23.8	50.2
WW+F	25 mm·wk^{-1}	2.7	3.7	104	225	24.5	52.3
Significance							
Water source		***	***	***	***	***	***
Irr. level		NS	**	NS	NS	NS	NS
Water x Irr.		NS	NS	NS	NS	NS	NS
Contrasts							
RCW vs RCW+F		***	***	***	***	***	**
RCW vs WW+F			*	*		**	***
RCW+F vs WW+F		**	***	**	*	***	

[z] RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water; SWD = soil water depletion.
[y] Subjective visual ratings ranged from 1 (a poorly growing, unhealthy tree) to 5 (a healthy, vigorous tree).
[x] Data represent the actual means, although data were statistically analyzed with analysis of covariance.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

Table 5.4. Visual rating, tree height and trunk diameter of young 'Redblush' grapefruit trees as affected by water source and irrigation level, Expt. 3 1991-92 and Expt. 4 1992 (Kanapaha sand, flatwoods).

Treatments[z]		Expt. 3						Expt.4		
		Visual rating[y]		Tree ht[x] (cm)		Trunk diam[x] (mm)		Visual rating[y]	Tree ht[x] (cm)	Trunk diam[x] (mm)
Water source	Irr. level	1991	1992	1991	1992	1991	1992		1992	
RCW+G	20% SWD	2.5	4.0	121	229	25.5	52.8	2.1	105	18.3
RCW+G	19 mm·wk^{-1}	2.9	4.2	127	234	26.2	52.8	2.3	101	19.6
RCW+G	25 mm·wk^{-1}	2.5	3.8	115	222	24.8	52.4	2.7	94	18.3
RCW+F	20% SWD	3.1	3.9	128	240	28.3	55.2	2.6	109	20.8
RCW+F	19 mm·wk^{-1}	3.5	3.9	129	236	29.5	58.1	2.5	109	21.3
RCW+F	25 mm·wk^{-1}	3.3	4.4	136	246	28.7	57.5	2.6	108	21.8
WW+F	20% SWD	1.8	3.1	124	217	25.6	48.0	2.1	106	18.8
WW+F	19 mm·wk^{-1}	2.1	3.2	130	215	25.2	48.7	2.7	116	21.3
WW+F	25 mm·wk^{-1}	2.6	4.3	131	232	26.8	51.9	2.5	114	19.8
Significance										
Water source		***	NS	NS	***	***	***	NS	**	***
Irr. level		NS	NS	NS	NS	NS	NS	NS	NS	NS
Water x Irr.		NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts										
RCW+G vs RCW+F		***			*	***	***		*	***
RCW+G vs WW+F		*					**		**	*
RCW+F vs WW+F		***			***	***	***			***

[z] RCW = simulated reclaimed wastewater; G = N-P-K-Mg granular fertilizer; F = N-K fertigation; WW = well water; SWD = soil water depletion.

[y] Subjective visual ratings ranged from 1 (a poorly growing, unhealthy tree) to 5 (a healthy, vigorous tree)

[x] Data represent actual means, although data were statistical analyzed by analysis of covariance.

NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

was evident for Expt. 2 in which height of the RCW+F trees was greater than those in other experiments (Table 5.3). For Expt. 3, tree height was similar for all treatments in 1991; however, in 1992 tree height of the RCW+F trees was significantly greater than trees in the other treatments (Table 5.4). Tree height for the RCW+F and WW+F trees was significantly greater than for the RCW+G trees in Expt. 4. (Table 5.4).

The RCW+F trees had significantly greater trunk diameters than the RCW or WW+F trees for Expt. 1 in 1990, 91 and 92 (Table 5.2). The same trend was evident for Expt. 2, in 1990 and 91 with the largest trunk diameter for the RCW+F trees (Table 5.3). For Expt. 3 in 1991 and 92, the RCW+F trees had significantly larger trunk diameters than the RCW+G or WW+F trees (Table 5.4). Similar results occurred in Expt. 4 (Table 5.4).

The use of reclaimed wastewater alone was insufficient to support adequate growth of young citrus trees as seen by the visual rating of canopy size and symptoms of N deficiency. Results were similar for grapes (Neilsen et al., 1989b), apples (Neilsen et al., 1989a) and cherries (Neilsen et al., 1991). However, when adequate nutrition was supplied, the trees receiving RCW+F had significantly larger trunk diameters and tree canopies than WW+F trees. These results are similar to those found by Koo and Zekri (1989) and Wheaton and Parsons (1993) for young citrus trees on the Ridge area of Florida. The increase in trunk diameter of RCW+F trees compared to trees in the other treatments suggest that frequent fertigation may increase growth as observed

by Willis et al. (1991) for 'Hamlin' orange trees on 'Carrizo' citrange rootstock growing in Arredondo fine sand.

Leaf tissue analysis

Leaf N concentration for Expt. 1 showed similar trends in 1990 and 91, with the highest leaf N levels for the WW+F trees, followed in sequence, by RCW+F and RCW trees (Table 5.5). Although, the RCW leaf tissue N concentration was in the optimum to excess range for mature citrus trees (Koo et al., 1984), these trees exhibited visual symptoms of N deficiency on the mature leaves and the younger leaves were not as dark-green in color as those in other treatments. Nitrogen deficiency was not detected in leaf samples possibly due to translocation of N from mature to new leaves. In 1992, the RCW trees were significantly lower in leaf N concentrations (deficient <2.0%) (Koo et al., 1984) than either the RCW+F or WW+F trees, which were near or in the optimum range (2.5-2.7%) for mature citrus trees (Koo et al., 1984). WW+F trees had significantly higher leaf N concentrations in Expt. 2 in 1990, followed by the RCW+F and RCW trees (Table 5.5). However, in 1991 the WW+F and RCW+F trees had similar leaf N concentrations which were significantly higher than those found in the RCW trees. The WW+F trees had significantly higher leaf N concentrations then the RCW+G or RCW+F trees for Expt. 3 in 1991 and 92. However, all trees in 1991 were in the excess range (> 3.0%). In 1992, the RCW+G and RCW+F trees were in the optimum range

Table 5.5. Leaf tissue nitrogen analysis for young 'Redblush' grapefruit trees 1990-92 as affected by water source and irrigation level, Expts. 1-4.[z]

Treatments[y]		(N % dry wt.)							
Water source	Irr. level	Expt. 1[v] 1990[x]	Expt. 1[v] 1991[x]	Expt. 1[v] 1992[w]	Expt. 2[v] 1990[x]	Expt. 2[v] 1991[x]	Expt. 3[v] 1991[x]	Expt. 3[v] 1992[w]	Expt. 4[v] 1992[w]
RCW (+G)[v]	20% SWD	2.5	2.9	1.8	2.1	2.1	3.2	2.4	3.0
RCW (+G)	19 mm·wk^{-1}	2.5	3.1	2.0	2.3	2.3	3.2	2.4	2.9
RCW (+G)	25 mm·wk^{-1}	2.6	3.2	2.1	2.4	2.4	3.2	2.4	2.8
RCW+F	20% SWD	3.3	3.5	2.5	3.2	2.7	3.2	2.4	2.6
RCW+F	19 mm·wk^{-1}	3.5	3.3	2.5	3.2	2.8	3.4	2.6	2.6
RCW+F	25 mm·wk^{-1}	3.0	3.5	2.4	3.3	2.9	3.5	2.4	2.6
WW+F	20% SWD	4.0	3.9	2.5	3.9	3.2	4.0	2.9	3.0
WW+F	19 mm·wk^{-1}	3.4	3.7	2.4	3.4	2.9	3.7	2.8	2.8
WW+F	25 mm·wk^{-1}	3.3	3.5	2.4	3.4	2.7	3.8	2.3	2.7
Significance									
Water source		***	***	***	***	***	***	**	***
Irr. level		**	NS	NS	NS	NS	NS	*	NS
Water x Irr.		**	**	*	*	*	NS	*	NS
Contrasts									
RCW (+G) vs RCW+F		***	***	***	***	***			***
RCW (+G) vs WW+F		***	***	***	***	***	***	**	
RCW+F vs WW+F		***	***		**		**	*	***

[z] Expt. 1 was conducted on an Arredondo fine sand (Ridge) and Expts. 2, 3 and 4 on a Kanapaha fine sand (flatwoods).
[y] RCW = simulated reclaimed wastewater; G = N-P-K-Mg granular fertilization; F= N-K fertigation; WW = well water; SWD = soil water depletion.
[x] Leaf tissue samples were taken from fully expanded final flush leaves in Dec. in 1990 and 91.
[w] Leaf tissue samples were taken from fully expanded spring flush leaves in Aug. 1992.
[v] The RCW treatment was used for Expts. 1 and 2 and the RCW+G treatment for Expts. 3 and 4.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$. 0.01 or 0.001, respectively.

while the WW+F trees had high leaf N levels (2.8-3.0%). Differences in N levels among years may be attributed to time of leaf sampling, since leaves were sampled from the final growth flush in Dec. 1991 rather than from fully expanded mature spring flush leaves in Aug. or Sept. 1992 as recommended by Koo et al. (1984). In Expt. 4, leaf N concentrations were significantly lower for the RCW+F trees compared to the RCW+G and WW+F trees; however, all trees were in the optimum to high range. No evidence of N deficiency was observed for Expts. 3 and 4.

Optimum leaf N concentration for mature citrus trees in Florida is 2.5-2.7% (Koo et al., 1984); however, our values for leaves sampled in 1990 and 91 represent fully expanded leaves from the third growth flush taken in December from young trees. Swietlik (1992) observed optimum leaf N averages from 2.7-2.8% for young 'Ray Ruby' grapefruit trees in Texas and Willis et al. (1990) found levels as high as 3.0% for leaves from young 'Hamlin' orange trees sampled in December. Likewise, Obreza and Rouse (1993) observed similar results for young 'Hamlin' orange trees. Our experiments indicate that for final flush leaves sampled in December, leaf N levels of 3.0% or higher may be considered optimum for young citrus trees. For leaves sampled at the recommended time, N standards of the leaf tissue appear to be adequate for young citrus trees. Leaf samples taken in December may be adequate for determining differences among treatments, but may not be suitable for comparisons to recommended standards.

The RCW trees had significantly higher leaf P concentrations (excess >0.3%) than the RCW+F or WW+F trees for Expt. 1 in 1990 and 92 (Table 5.6). RCW trees had excess leaf P levels, while trees in the other treatments were in the optimum range (0.12-0.16%) (Koo et al., 1984). In 1991, the RCW and WW+F trees had significantly higher leaf P than the RCW+F trees. Trees in Expt. 2 exhibited similar trends in leaf P as Expt. 1. For Expts. 3 and 4, the WW+F trees had significantly higher leaf P. Although there were significant differences in leaf P for Expts. 3 and 4, levels were typically in the optimum to high range. The elevated leaf P concentrations for the RCW trees in Expts. 1 and 2 may have been due to the reduced growth which concentrates P in the leaves. In addition, N competes with P in the soil and decreased N levels may account for elevated leaf P levels in citrus leaves (Smith and Reuther, 1954).

Leaf K concentrations for Expt. 1 were similar among trees in 1990 and 92 (Table 5.7). However, in 1991 the RCW trees were significantly lower in leaf K than the RCW+F or WW+F trees. All trees had similar leaf K concentrations for Expt. 2 in 1990. However, in 1991, the RCW trees had significantly lower leaf K concentrations than trees in the other treatments. The higher leaf K levels for the RCW+F and WW+F trees may be attributed to these trees receiving additional K in the liquid fertilizer. Trees in Expt. 3 had similar trends in 1991 and 92, ie., significantly lower leaf K for the RCW+G trees than trees in the other treatments, possibly due to frequency and form of K applied to these treatments. However, all trees were in the optimum range (1.2-1.7%) for leaf K.

Table 5.6. Leaf tissue phosphorus analysis for young 'Redblush' grapefruit trees 1990-92 as affected by water source and irrigation level, Expts. 1-4.[z]

Treatments[y]		(P % dry wt.)							
Water source	Irr. level	Expt. 1[v]			Expt. 2[v]		Expt. 3[v]		Expt. 4[v]
		1990[x]	1991[x]	1992[w]	1990[x]	1991[x]	1991[x]	1992[w]	1992[w]
RCW (+G)[v]	20% SWD	0.37	0.21	0.33	0.33	0.26	0.16	0.10	0.14
RCW (+G)	19 mm·wk^{-1}	0.42	0.19	0.34	0.47	0.27	0.16	0.11	0.14
RCW (+G)	25 mm·wk^{-1}	0.42	0.17	0.25	0.44	0.24	0.17	0.10	0.15
RCW+F	20% SWD	0.19	0.14	0.11	0.19	0.14	0.16	0.10	0.12
RCW+F	19 mm·wk^{-1}	0.19	0.14	0.12	0.18	0.15	0.16	0.11	0.15
RCW+F	25 mm·wk^{-1}	0.19	0.19	0.12	0.19	0.15	0.17	0.11	0.15
WW+F	20% SWD	0.20	0.19	0.11	0.20	0.18	0.21	0.12	0.19
WW+F	19 mm·wk^{-1}	0.19	0.18	0.13	0.19	0.16	0.19	0.12	0.15
WW+F	25 mm·wk^{-1}	0.20	0.17	0.13	0.19	0.16	0.17	0.12	0.17
Significance									
Water source		***	**	***	***	***	***	***	***
Irr. level		NS	NS	NS	NS	NS	NS	**	NS
Water x Irr.		NS	NS	NS	*	NS	NS	NS	NS
Contrasts									
RCW (+G) vs RCW+F		***	***	***	***	***			
RCW (+G) vs WW+F		***		***	***	***	***	***	***
RCW+F vs WW+F			**				**	***	***

[z] Expt. 1 was conducted on an Arredondo fine sand (Ridge) and Expts. 2, 3 and 4 on a Kanapaha fine sand (flatwoods).
[y] RCW = simulated reclaimed wastewater; G = N-P-K-Mg granular fertilization; F= N-K fertigation; WW = well water; SWD = soil water depletion.
[x] Leaf tissue samples were taken from fully expanded final flush leaves in Dec. in 1990 and 91.
[w] Leaf tissue samples were taken from fully expanded spring flush leaves in Aug. 1992.
[v] The RCW treatment was used for Expts. 1 and 2 and the RCW+G treatment for Expts. 3 and 4.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$. 0.01 or 0.001, respectively.

Table 5.7. Leaf tissue potassium analysis for young 'Redblush' grapefruit trees 1990-92 as affected by water source and irrigation level, Expts. 1-4.[z]

Treatments[y]		(K % dry wt.)							
Water source	Irr. level	Expt. 1[v]			Expt. 2[v]		Expt. 3[v]		Expt. 4[v]
		1990[x]	1991[x]	1992[w]	1990[x]	1991[x]	1991[x]	1992[w]	1992[w]
RCW (+G)[v]	20% SWD	1.4	1.1	1.3	1.7	1.1	1.3	1.3	1.9
RCW (+G)	19 mm·wk^{-1}	2.0	1.3	1.5	2.2	1.4	1.3	1.4	1.8
RCW (+G)	25 mm·wk^{-1}	2.0	1.3	1.5	2.0	1.3	1.3	1.5	1.7
RCW+F	20% SWD	1.8	1.6	1.3	1.8	1.3	1.5	1.5	1.9
RCW+F	19 mm·wk^{-1}	2.0	1.6	1.3	1.8	1.5	1.6	1.6	2.0
RCW+F	25 mm·wk^{-1}	1.9	1.4	1.3	1.9	1.4	1.6	1.5	2.1
WW+F	20% SWD	2.0	1.6	1.3	1.8	1.5	1.5	1.5	1.8
WW+F	19 mm·wk^{-1}	1.8	1.5	1.4	1.9	1.6	1.6	1.6	1.8
WW+F	25 mm·wk^{-1}	1.9	1.6	1.4	1.9	1.5	1.6	1.5	1.9
Significance									
Water source		NS	***	NS	NS	***	***	***	*
Irr. level		*	NS	NS	**	NS	NS	NS	NS
Water x Irr.		**	*	NS	NS	NS	NS	NS	*
Contrasts									
RCW (+G) vs RCW+F			***				***	***	**
RCW (+G) vs WW+F			***			***	***	**	
RCW+F vs WW+F						*			*

[z] Expt. 1 was conducted on an Arredondo fine sand (Ridge) and Expts. 2, 3 and 4 on a Kanapaha fine sand (flatwoods).
[y] RCW = simulated reclaimed wastewater; G = N-P-K-Mg granular fertilization; F = N-K fertigation; WW = well water; SWD = soil water depletion.
[x] Leaf tissue samples were taken from fully expanded final flush leaves in Dec. 1990 and 91.
[w] Leaf tissue samples were taken from fully expanded spring flush leaves in Aug. 1992.
[v] The RCW treatment was used for Expts. 1 and 2 and the RCW+G treatment for Expts. 3 and 4.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

Similar results were seen for Expt. 4, except leaf K was in the high range (1.8-2.3%) (Koo et al., 1984). Similar to leaf P, the levels of K were in the optimum to high range for citrus trees and, although mean levels were statistically significant, there is little practical difference among treatments.

The WW+F trees for Expt. 1 in 1990 and 92 had significantly lower leaf Na concentrations than trees in the other treatments (Table 5.8). In 1991, all leaf Na concentrations were statistically significant; however, all leaf Na concentrations were below the excess level > 2500 $\mu g \cdot g^{-1}$ (Embleton et al., 1973). For Expt. 2, all leaf Na concentrations were within the acceptable range. The RCW+F trees had significantly higher leaf Na concentrations than the RCW+G and WW+F trees for Expt. 3 in 1991 and 92. Similarly, for Expt. 4, the RCW+F trees had the highest leaf Na concentrations followed by RCW+G and WW+F trees. In general, the RCW, RCW+G, and RCW+F trees had higher leaf Na levels than trees in the WW+F treatments. The increase in leaf Na concentrations for trees receiving reclaimed wastewater can be attributed to the higher levels of Na in the irrigation waters. Likewise, Zekri and Koo (1993) observed an increase in leaf Na concentration for trees receiving reclaimed wastewater compared to trees receiving well water. Although leaf Na concentrations were higher for trees in the RCW, RCW+G and RCW+F treatments, no toxicity symptoms were observed.

Leaf B concentrations for Expt. 1 were similar for all 3 years, with the RCW and RCW+F trees significantly higher in leaf B than the WW+F trees

Table 5.8. Leaf tissue sodium analysis for young 'Redblush' grapefruit trees 1990-92 as affected by water source and irrigation level, Expts. 1-4.[z]

Treatments[y]		(Na $\mu g \cdot g^{-1}$ dry wt.)							
Water source	Irr. level	Expt. 1[v]			Expt. 2[v]		Expt. 3[v]		Expt. 4[v]
		1990[x]	1991[x]	1992[w]	1990[x]	1991[x]	1991[x]	1992[w]	1992[w]
RCW (+G)[v]	20% SWD	310	610	830	310	538	730	912	1470
RCW (+G)	19 mm·wk^{-1}	805	613	760	818	517	780	1040	1750
RCW (+G)	25 mm·wk^{-1}	1120	703	870	585	598	850	1240	2880
RCW+F	20% SWD	648	773	670	410	530	740	1140	2390
RCW+F	19 mm·wk^{-1}	983	785	780	708	538	1080	1200	2470
RCW+F	25 mm·wk^{-1}	835	930	1080	828	618	1400	1480	2740
WW+F	20% SWD	265	758	670	468	468	910	885	470
WW+F	19 mm·wk^{-1}	225	695	570	775	498	810	848	420
WW+F	25 mm·wk^{-1}	350	743	600	370	485	590	878	460
Significance									
Water source		***	***	***	NS	NS	***	***	***
Irr. level		**	*	*	***	NS	NS	**	NS
Water x Irr.		*	NS	*	NS	NS	***	NS	NS
Contrasts									
RCW (+G) vs RCW+F			***				**	**	
RCW (+G) vs WW+F		***	*	**			*	**	***
RCW+F vs WW+F		***	*	***			***	***	***

[z] Expt. 1 was conducted on an Arredondo fine sand (Ridge) and Expts. 2, 3 and 4 on a Kanapaha fine sand (flatwoods).
[y] RCW = simulated reclaimed wastewater; G = N-P-K-Mg granular fertilization; F = N-K fertigation; WW = well water; SWD = soil water depletion.
[x] Leaf tissue samples were taken from fully expanded final flush leaves in Dec. 1990 and 91.
[w] Leaf tissue samples were taken from fully expanded spring flush leaves in Aug. 1992.
[v] The RCW treatment was used for Expts. 1 and 2 and the RCW+G treatment for Expts. 3 and 4.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

(Table 5.9). A similar trend was seen in Expts. 2, 3 and 4. Even though the WW+F trees for all experiments were significantly lower in leaf B, levels were in the optimum range (36-100 $\mu g \cdot g^{-1}$) (Koo et al., 1984). In contrast, the RCW, RCW+G and RCW+F trees were usually in the high range (100-200 $\mu g \cdot g^{-1}$). Rarely did levels reach excess (> 200 $\mu g \cdot g^{-1}$) and no toxicity symptoms were observed. Similar increases in leaf B have been observed for peaches (Basiouny, 1984), apples (Neilsen et al., 1989a) and citrus (Zekri and Koo, 1993) irrigated with reclaimed wastewater. Our results indicate that reclaimed wastewater, which often contains B concentrations of 0.5-1.0 mg·liter^{-1} (Kirkham, 1986), is acceptable for citrus tree irrigation and additional applications of B are not necessary. Similarly other researchers found no toxicity problems when using irrigation water containing < 1.0 mg·liter^{-1} B, although toxicity symptoms occurred for trees irrigated with water containing ≥ 2.0 mg·liter^{-1} B (Cooper and Edwards, 1950; Cooper and Peynado, 1959; Peynado and Cooper, 1962; Smith and Reuther, 1951).

Leaf Ca was similar for all treatments and experiments with levels near or within the optimum range (3.0-4.9%) (Koo et al.,1984) (data not shown) Reclaimed wastewater and well water had similar Ca concentrations. Leaf Mg concentrations for the RCW, RCW+G and RCW+F treated trees were consistently higher (optimum, 0.30-0.49%) than the WW+F trees (low, 0.20-0.29) for all experiments because the reclaimed wastewater contained more than twice the level of Mg as the well water (data not shown). Leaf Cl

Table 5.9. Leaf tissue boron analysis for young 'Redblush' grapefruit trees 1990-92 as affected by water source and irrigation level, Expts. 1-4.[z]

Treatments[y]		(B $\mu g \cdot g^{-1}$ dry wt.)							
Water source	Irr. level	Expt. 1[v]			Expt. 2[v]		Expt. 3[v]		Expt. 4[v]
		1990[x]	1991[x]	1992[w]	1990[x]	1991[x]	1991[x]	1992[w]	1992[w]
RCW (+G)[v]	20% SWD	90	79	136	72	90	92	112	233
RCW (+G)	19 mm·wk^{-1}	104	88	140	109	107	111	121	221
RCW (+G)	25 mm·wk^{-1}	134	90	157	94	108	119	129	207
RCW+F	20% SWD	48	70	96	56	77	83	102	174
RCW+F	19 mm·wk^{-1}	81	96	131	78	116	103	113	188
RCW+F	25 mm·wk^{-1}	97	111	160	95	124	96	130	210
WW+F	20% SWD	80	37	29	38	43	42	51	56
WW+F	19 mm·wk^{-1}	22	26	26	43	70	46	39	121
WW+F	25 mm·wk^{-1}	19	30	28	30	35	41	32	64
Significance									
Water source		***	***	***	***	***	***	***	***
Irr. level		***	**	***	***	***	**	NS	NS
Water x Irr.		***	**	***	**	*	NS	***	NS
Contrasts									
RCW (+G) vs RCW+F		***		***	**		**		
RCW (+G) vs WW+F		***	***	***	***	***	***	***	***
RCW+F vs WW+F		***	***	***	***	***	***	***	***

[z] Expt. 1 was conducted on an Arredondo fine sand (Ridge) and Expts. 2, 3 and 4 on a Kanapaha fine sand (flatwoods).
[y] RCW = simulated reclaimed wastewater; G = N-P-K-Mg granular fertilization; F = N-K fertigation; WW = well water; SWD = soil water depletion.
[x] Leaf tissue samples were taken from fully expanded final flush leaves in Dec. 1990 and 91.
[w] Leaf tissue samples were taken from fully expanded spring flush leaves in Aug. 1992.
[v] The RCW treatment was used for Expts. 1 and 2 and the RCW+G treatment for Expts. 3 and 4.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

concentrations were similar for all treatments because the RCW, RCW+G and RCW+F trees received Cl in the reclaimed wastewater and the WW+F trees received Cl from fertigation as potassium chloride (data not shown). Although the reclaimed wastewater and fertigation provided various levels of Cl, soluble salts do not accumulate in the soil if sufficient water or rainfall leach excess salts from the root zone (Basiouny, 1982; Kirkham, 1986). Leaf Cu and Mn were generally within the optimum range, while Fe was typically in the high range and Zn was in the low to deficient for all experiments and treatments (Koo et al., 1984) (data not shown). The similar leaf Cu, Fe, Mn and Zn concentrations are attributed to the reclaimed wastewater and well water having relatively low levels of these nutrients. In addition, Zekri and Koo (1992) found that uptake of micronutrients applied through fertigation was dependent on the form of the nutrient applied as chelated nutrients are available for plant uptake and not absorbed onto the soil particles.

Fruit yield and quality

Bloom intensity was rated from 1 (no bloom) to 5 (75-100% full bloom). Bloom intensity was similar for all trees for Expt. 1 in 1991 (data not shown). In 1992, bloom intensity of the RCW+F trees was significantly increased compared to the RCW or WW+F trees. Bloom intensity averaged 3.8, 1.5 and 1.2 for the RCW+F, WW+F and RCW trees, respectively. Similarly, yield was significantly greater for the RCW+F trees (77 kg/tree) followed by WW+F (11

kg/tree) and RCW (1.3 kg/tree) trees as was fruit number (194.0, 31.7 and 3.3 fruit/tree average for the RCW+F, WW+F and RCW trees, respectively). Average fruit weight, juice weight, peel thickness, TSS, TA and TSS:TA ratio were similar for all treatments (data not shown). Fruit quality was not analyzed for the RCW trees due to insufficient fruit numbers.

Substantial increases in bloom and yield for the RCW+F trees compared to the WW+F trees is difficult to explain. Similar yield increases have been reported for citrus (Koo and Zekri, 1989; Omran et al., 1988; Wheaton and Parsons, 1993), peaches (Basiouny, 1984), cherries (Neilsen et al., 1991) and apples (Neilsen et al., 1989a) from the use of reclaimed wastewater. Trees receiving RCW alone were obviously N deficient based on visual observations and leaf tissue analysis. However, the only consistent difference between the RCW+F and WW+F trees is leaf B concentration. Leaf B concentration for the WW+F trees was in the low end of the optimum range, while leaf B was in the upper optimum to high range for the RCW+F trees. There is growing evidence that B may play a significant role in yield responses. Foliar sprays of B at bloom significantly increased fruit set and yield in trees considered to have optimum leaf B levels such as cherries (Hanson, 1991), avocados (Robbertse et al., 1990), hazelnuts (Shrestha et al., 1987) and prunes (Hanson and Breen, 1985).

Increased B levels have been shown to reduce pistil length bringing the stigma closer to the anthers and enhancing pollen transfer in prunes (Hanson

and Breen, 1987), however this is unlikely to account for the substantial increase in fruit set observed with B applications. Boron was required for pollen germination (Lewis, 1980) and high B concentrations in the style were needed for optimal pollen tube growth thus increasing fruit set (Robbertse et al., 1990). Although B may be present in the leaves, there is limited remobilization from leaves to the buds (Hanson and Breen, 1985). Therefore, free B is needed during flowering for transport to the flowers (Robbertse et al., 1990). Thus, the frequent application of B from reclaimed wastewater treatments may provide a constant supply of B at critical times of flower development particularly as the xylem and floral bud become connected 5 weeks before bloom (Hanson and Breen, 1985). In contrast, Smith and Reuther (1951), observed no differences in fruit set or yield for 'Valencia' orange trees irrigated with water containing B at 0.01, 0.5 and 2.0 $mg \cdot liter^{-1}$. These data are from only one year and further research is necessary to substantiate these results.

The use of reclaimed municipal wastewater has great potential in both the Ridge and flatwoods areas of Florida for newly planted citrus trees. Reclaimed wastewater alone does not supply enough plant nutrients to support adequate tree growth. However, with additional fertilization, trees irrigated with RCW+F were consistently larger than those irrigated with well water regardless of fertilization method; fertigated trees were significantly larger than those fertilized with granular fertilizer. Reclaimed wastewater increased

leaf Na and B, but levels were not phytotoxic and no deleterious effects were observed. In addition, young citrus trees receiving the RCW+F had significant increases in bloom and yield.

CHAPTER VI

LEAF NITROGEN CONTENT EFFECTS ON FREEZE HARDINESS OF YOUNG 'REDBLUSH' GRAPEFRUIT TREES

Introduction

The magnitude and range of citrus production in Florida has historically been limited due to low temperatures, with severe freezes occurring about once every 10 years (Yelenosky, 1985). The role citrus tree nutrient status plays in freeze hardiness has been examined for years. Post-freeze evaluations indicate that the levels of Zn, Cu (Lawless, 1941), Mn (Swietlik and LaDuke, 1985), Mg (Lawless, 1941), P (Koo, 1985a; Spencer, 1958; Spencer, 1960), K (Koo, 1985a; Smith and Rasmussen, 1958) and N (Cheong and Moon, 1989; Koo, 1985a; Sharples and Burkhart, 1953; Smith and Rasmussen, 1958) are correlated with freeze tolerance of citrus trees. Conversely, Smith and Rasmussen (1958) reported that nutrient levels have relatively small effects on citrus tree freeze hardiness when obvious deficiencies are absent.

Some studies suggest that late fall applications of N fertilizer should be avoided to prevent stimulating growth, and thus delaying the onset of

nonapparent growth which increases freeze susceptibility (Hume, 1956; Krezdorn and Martsolf, 1984; Smith and Rasmussen, 1958). For example, more branch dieback was observed for trees in plots receiving high N vs. low N (Koo, 1981). Conversely, less freeze damage was observed for mature 'Marsh' grapefruit trees with leaf N levels of 2.84% compared to 2.64%, with a similar trend occurring for mature 'Valencia' orange trees (Smith and Rasmussen, 1958). Similarly, Koo (1985a) observed an increase in freeze damage when leaf N content was below 2.5% compared to 2.5-2.8%. In Korea, Cheong and Moon (1989) found that of the nutrients tested only leaf N content showed a positive correlation with leaf freezing tolerance, but excessive N fertilization did not increase freezing tolerance.

Citrus trees acclimate and deacclimate depending on air and soil temperatures (Rouse and Wiltbank, 1972; Wilcox et al., 1983; Young and Peynado, 1965). In Florida, fluctuations in air temperature may cause trees to acclimate and deacclimate several times during the winter (Wiltbank and Oswalt, 1983). Air temperatures below 10C increase freeze hardiness of citrus trees (Rouse and Wiltbank, 1972), but lower temperatures of long durations increase acclimation rate (Young and Peynado, 1965). Increased freeze hardiness was apparent within 2 weeks after induction of acclimating temperatures (Yelenosky, 1978), but deacclimation occurred within 1 week (Young and Peynado, 1965)

Therefore, the general consensus seems to be that low or high levels of N (outside normal ranges) decrease leaf freeze hardiness. Nevertheless, most studies are based on post-freeze evaluations of trees and results are often contradictory. The objective of these studies was to determine the effects of leaf nutrient concentration on freeze hardiness of young citrus trees in the field throughout the winter.

Materials and Methods

Two field experiments were used to evaluate the effects of leaf N concentrations on freeze hardiness of young citrus trees. Trees used in this experiment (Expt. 1) were part of a reclaimed wastewater irrigation experiment and had received different levels of N throughout the year (Chapter V, Expt. 1). A 10 leaf sample was collected from fully expanded leaves from the fall flush in Nov. 1991 and 92. Leaf N content was then determined as described previously (Chapter III, p 44). Five trees from each of the RCW, RCW+F and WW+F treatments were selected based on leaf N concentration. The RCW, RCW+F and WW+F trees had leaf N concentrations ranging from 2.0-2.2, 2.6-2.8 and 3.6-3.8% in 1991 and 2.3-2.6, 3.0-3.1 and 3.0% in 1992, respectively.

Mature fully expanded fall flush leaves were randomly selected with 10 leaves/tree from five trees/treatment on 12 Jan., 7, 22 Feb., 6 and 21 Mar. 1992 to determine changes in leaf freeze hardiness (Gerber and Hashemi, 1964; Hutcheson and Wiltbank, 1970). In 1992-93 12 leaves/tree from five

trees/treatment were collected on 21 Nov., 7, 14, 25 Dec. 1992 and 11, 25 Jan., 1, 5, 11, 18 and 26 Feb. 1993. Leaves were cut and immediately placed in an air tight plastic bag in an ice chest for transport to the laboratory for determination of leaf killing point (LKP) by electrolyte leakage and visual rating methods. Leaves were wiped with a moist Kimwipe (Kimberly-Clark, Neenah, WI) to remove dust and surface contaminants. Each leaf was then placed with the petiole at the bottom of a 25 x 200 mm test tube. A small amount of ice was added to each test tube as a source of ice nucleation and a rubber stopper placed on each test tube to prevent ethylene glycol intrusion from the freeze-bath.

Temperature ranges for determining LKPs were selected in increments of 1C in both seasons (i.e., -3, -4, -5, -6 and -7C). The temperature range was adjusted during the season to adjust for acclimation and deacclimation of the leaves (Rouse and Wiltbank, 1972; Rouse et al., 1977; Wiltbank and Oswalt, 1983). Ten replicate test tubes were placed in a weighted rack and lowered into an ethylene glycol bath (Forma Scientific model 2425 Marietta, OH) pre-cooled to -1C and then lowered to a temperature slightly higher than the anticipated LKP. After 1 h at the initial temperature, 10 of the test tubes/treatment were removed and the bath temperature lowered by 1C. The remaining test tubes were held 1 h at this temperature after which another set of 10 test tubes/treatment was removed. This process was continued until all test tubes were removed from the ethylene glycol bath. Upon removal from the

ethylene glycol bath leaves were allowed to thaw in the test tubes at 26C. Leaves were then removed from the test tubes and one leaf placed in a petri dish for visual ratings and a duplicate leaf sectioned transversely into 7 mm sections. The sectioned leaf was then placed in a clean test tube with 25 ml of deionized distilled water. Leaf sections were allowed to incubate at 26C for 24 h (Anderson et al., 1983). The solution was decanted from each test tube and the initial conductivity measured using a conductivity meter (Radiometer model CDM 3, Copenhagen, Denmark). Leaf sections were then frozen for 4-6 h at -20C, and the decanted solution reintroduced to the frozen leaf tissue. After another 24 h of incubation at 26C, the solution was again decanted and final conductivity measured. Percentage conductivity was calculated as 100 x (initial / final conductivity). Plots of % conductivity vs temperature produced sigmoid curves with the inflection point being the LKP (Anderson et al., 1983; Wiltbank and Oswalt, 1983).

Leaves placed in the petri dish were held at 20C in an incubator and were rated visually five to seven days following freeze treatments from 0 (no damage) to 10 (100% damage) based on leaf area damaged. LKPs were determined by plotting leaf damage rating vs. temperature.

Trees in Expt. 2 were also part of a reclaimed wastewater irrigation experiment and had received different levels of N during the season (Chapter V, Expt. 2). Trees in Expt. 2 were evaluated following a freeze on 17 Jan., 1992

where minimum air temperature reached -6.5C, with air temperatures ≤ -6.0C for 3 h.

Visual evaluations of leaf damage were made on 11 Feb. 1992 and values ranged from 1 (no leaf damage) to 5 (> 50% leaf damage). In addition, three shoots per tree from the fall flush were randomly selected and evaluated based on percentage of leaf loss. A 10 leaf sample was collected from each tree for leaf tissue analysis of N, P, K, Ca and Mg levels. Leaf preparation and analysis was the same as described previously (Chapter III, p 44).

Leaf tissue analysis and post-freeze observations were statistically analyzed as a factorial in a completely randomized block design. The SAS general linear model (GLM) procedure was used to perform analysis of variance for both experiments. Contrasts were used to determine trends in the data and separate means.

Results and Discussion

Leaf tissue freeze hardiness, Fifield (Expt. 1)

Leaves were separated into three treatments based on leaf N levels in 1991-92 and ranged from 2.0-2.2%, 2.6-2.8% and 3.6-3.8% N for the RCW, RCW+F and WW+F trees, respectively. All leaves had similar LKPs on 12 Jan. and 7 Feb. 1992 which averaged -5.9 and -6.4C, respectively, as determined by the electrolyte leakage method (Table 6.1). However, on 22 Feb. and 6 Mar. 1992, the WW+F leaves had significantly higher LKPs (-4.9 and -4.6C) than the

Table 6.1. Effects of leaf nutrient content on leaf killing point (LKP) of 'Redblush' grapefruit leaves determined by the electrolyte leakage method, 1991-92.[z]

Treatments[y]	12 Jan.	7 Feb.	22 Feb.	6 Mar.	21 Mar.
			LKP (C)		
RCW - (2.0-2.2% N)	-5.7	-6.5	-5.5	-5.2	-4.1
RCW+F - (2.6-2.8% N)	-6.2	-6.2	-6.0	-5.7	-4.5
WW+F - (3.6-3.8% N)	-5.9	-6.5	-4.9	-4.6	-3.4
Significance					
Treatment	NS	NS	**	*	*
Contrasts[x]					
RCW vs. WW+F					*
RCW+F vs. WW+F			**	*	**

[z] Numbers represent the means of LKPs from 5 trees/treatment.
[y] RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water.
[x] Only significant contrasts are presented.
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

RCW+F leaves (-6.0 and -5.7C), respectively. Furthermore, on 21 Mar. the RCW and RCW+F leaves had significantly lower LKPs (-4.1 and -4.5C) than the WW+F leaves (-3.4C).

LKPs determined by the visual rating method were similar on 7 Feb., and 6 Mar. and averaged -8.2 and -5.1C, respectively (Table 6.2). However, on 22 Feb. the RCW leaves had a significantly higher LKP (-6.5C) than the RCW+F (-7.1C) and WW+F (-7.2C) leaves. In contrast, on 21 Mar., the RCW leaves had a significantly lower LKP (-4.9C) than the WW+F (-4.2C) leaves. LKPs from the visual ratings had lower predicted values than those from the electrolyte leakage method. Although differences in LKPs were statistically significant, differences among treatments were typically 1C or less.

In 1992-93, fertilizer treatments did not produce the wide range in leaf N concentrations as in 1991-92. Leaf N concentrations were 2.3-2.6, 3.0-3.1 and 3.0% for the RCW, RCW+F and WW+F trees, respectively. The WW+F trees which previously had leaf N concentrations of 3.6-3.8% in 1991-92 had similar N levels to the RCW+F trees. LKPs were similar for all leaves on 21 Nov., 7 Dec., 11, 25 Jan., 5, 11 and 18 Feb. and averaged -5.4, -5.6, -5.3, -5.7, -8.1, -5.8 and -5.9C, respectively (Table 6.3). However, on 14 Dec. leaves from the WW+F trees had a significantly higher LKP (-6.9C) than leaves from the RCW (-7.5C) and RCW+F (-7.9C) treatments. LKPs on 28 Dec. were significantly lower for the RCW+F leaves (-6.7C) than the RCW (-5.5C) and WW+F (-5.7C) leaves. The WW+F leaves had a significantly lower LKP (-8.6C) than the RCW

Table 6.2. Effects of leaf nutrient content on leaf killing point (LKP) of 'Redblush' grapefruit leaves determined by the visual rating method, 1991-92.[z]

Treatments[y]	12 Jan.	7 Feb.	22 Feb.	6 Mar.	21 Mar.
			LKP (C)		
RCW - (2.0-2.2% N)	[x]	-8.0	-6.5	-5.0	-4.9
RCW+F - (2.6-2.8% N)	[x]	-8.3	-7.1	-5.5	-4.3
WW+F - (3.6-3.8% N)	[x]	-8.4	-7.2	-4.9	-4.2
Significance					
Treatment		NS	*	NS	*
Contrasts[w]					
RCW vs. RCW+F			*		
RCW vs. WW+F			*		*

[z] Numbers represent the means of LKPs from 5 trees/treatment.
[y] RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water.
[x] Missing data.
[w] Only significant contrast are presented.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 6.3. Effects of leaf nutrient content on leaf killing point (LKP) of 'Redblush' grapefruit leaves determined by the electrolyte leakage method, 1992-93.[z]

Treatments[y]	21 Nov	7 Dec.	14 Dec.	28 Dec.	11 Jan.	25 Jan.	1 Feb.	5 Feb.	11 Feb.	18 Feb.	26 Feb.
	LKP (C)										
RCW - (2.3-2.6% N)	-5.4	-5.4	-7.5	-5.5	-5.1	-5.7	-8.0	-8.1	-6.1	-6.3	-7.5
RCW+F - (3.0-3.1% N)	-5.3	-5.8	-7.9	-6.7	-5.5	-5.7	-7.9	-8.2	-5.7	-5.4	-6.9
WW+F - (3.0% N)	-5.5	-5.6	-6.9	-5.7	-5.3	-5.8	-8.6	-8.1	-5.5	-6.1	-5.9
Significance											
Treatment	NS	NS	**	**	NS	NS	**	NS	NS	NS	**
Contrasts											
RCW vs. RCW+F				**							
RCW vs. WW+F			*				**				**
RCW+F vs. WW+F			**	**			***				*

[z] Numbers represent the means of LKPs from 5 trees/treatment.
[y] RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

(-8.0C) and RCW+F (-7.9C) leaves on 1 Feb., but the inverse was found on 26 Feb with LKPs of -8.4, -8.0 and -8.0C for the RCW, RCW+F and WW+F leaves, respectively. LKPs determined by electrolyte leakage were similar for 7 of the 11 evaluation dates with no consistent differences in leaf N on leaf freezing tolerance.

LKPs determined by visual ratings were similar on 11 Jan., 5 and 26 Feb. and averaged -6.1, -8.7 and -8.1C, respectively (Table 6.4). However, on 7 Dec. the RCW leaves had a significantly higher LKP (-6.5) than the RCW+F (-7.4) and WW+F (-8.0C) leaves, but on 14 Dec. the inverse occurred with LKPs of -8.4, -8.0 and -8.0C for the RCW, RCW+F and WW+F leaves, respectively. On 28 Dec. the RCW+F leaves had a significantly lower LKP (-7.8C) than the RCW (-6.9C) and WW+F (-6.8C) leaves. The WW+F leaves had a significantly higher LKP (-7.1C) than the RCW (8.1C) and RCW+F (-7.7C) leaves on 25 Jan. On 1 Feb. the RCW+F (-8.0C) leaves had a significantly higher LKP than the RCW (-8.4C) and WW+F (-8.4C) leaves. LKP on 11 Feb. was significantly lower for the RCW leaves (-8.2) compared to the RCW+F (-7.2C) and WW+F (-7.1C) leaves, but on 18 Feb. only the RCW+F leaves (-6.2C) had a significantly higher LKP than the RCW (-7.4C) leaves. Differences in LKPs determined by visual ratings were statistically significant on 7 of the 10 evaluation dates, but no consistent trends in leaf N were observed in freeze tolerance. Although the LKPs determined by the electrolyte leakage method were typically about 1C

Table 6.4. Effects of leaf nutrient content on leaf killing point (LKP) of 'Redblush' grapefruit leaves determined by the visual rating method, 1992-93.[z]

Treatments[y]	7 Dec.	14 Dec.	28 Dec.	11 Jan	25 Jan.	1 Feb.	5 Feb.	11 Feb.	18 Feb.	26 Feb.
	LKP (C)									
RCW - (2.3-2.6% N)	-6.5	-8.3	-6.9	-5.8	-8.1	-8.4	-8.4	-8.2	-7.4	-8.5
RCW+F - (3.0-3.1% N)	-7.4	-8.0	-7.8	-6.4	-7.7	-8.0	-8.7	-7.2	-6.2	-8.2
WW+F - (3.0% N)	-8.0	-8.0	-6.8	-6.2	-7.1	-8.4	-9.0	-7.1	-6.7	-7.7
Significance										
Treatment	**	*	**	NS	*	**	NS	*	*	NS
Contrasts										
RCW vs. RCW+F	*	*	**			**		*	*	
RCW vs. WW+F	**	*			**			*		
RCW+F vs. WW+F			**		*	**				

[z] Numbers represent the means of LKPs from 5 trees/treatment.
[y] RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water;
NS,*,**,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

higher than the visual rating method, both methods gave similar trends in leaf freezing tolerances related to treatments.

Leaf freeze hardiness varied throughout the season as trees acclimated and deacclimated. Leaf freeze hardiness closely followed changes in air temperature (Figs. 6.1-2). In 1991-92, average air temperatures in December began to decline as well as minimum air temperatures below 10C leaf freeze hardiness increased until 7 Feb. when all leaves reached their maximum freeze hardiness. From mid-Feb. through Mar. average air temperatures increased and the leaves began to deacclimate. Although there were periods of low temperatures during this time, leaves continued to deacclimate. Rouse and Wiltbank (1972) found that air temperatures below 10C correlated with leaf freeze hardiness in one year but not the other. Air temperatures below 10C may not have an acclimating effect on leaf freeze hardiness in the spring when trees began a new growth flush as was the case in spring 1992. Similarly, in 1992-93, changes in average air temperature correlated with an increased or decreased in leaf freeze hardiness. However, there were two distinct periods of acclimation and deacclimation in 1992-93. Leaf freeze hardiness was greatest on 14 Dec. and again on 5 Feb. separated by a period of deacclimation and acclimation. Although trees had begun to produce a new growth flush at the end of February, the mature leaves appeared to be acclimating a third time.

Air temperatures have long been known to influence citrus leaf freeze hardiness (Rouse and Wiltbank, 1972; Rouse et al., 1977; Wiltbank and Oswalt,

Fig. 6.1. Average, maximum and minimum daily air temperatures (A), Leaf killing point determined by the electrolyte leakage method(B), Leaf killing point determined by the visual rating method (C), in 1991-92. RCW = 2.0-2.2% N, RCW+F = 2.6-2.8% N and WW+F = 3.6-3.8% N. RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water.

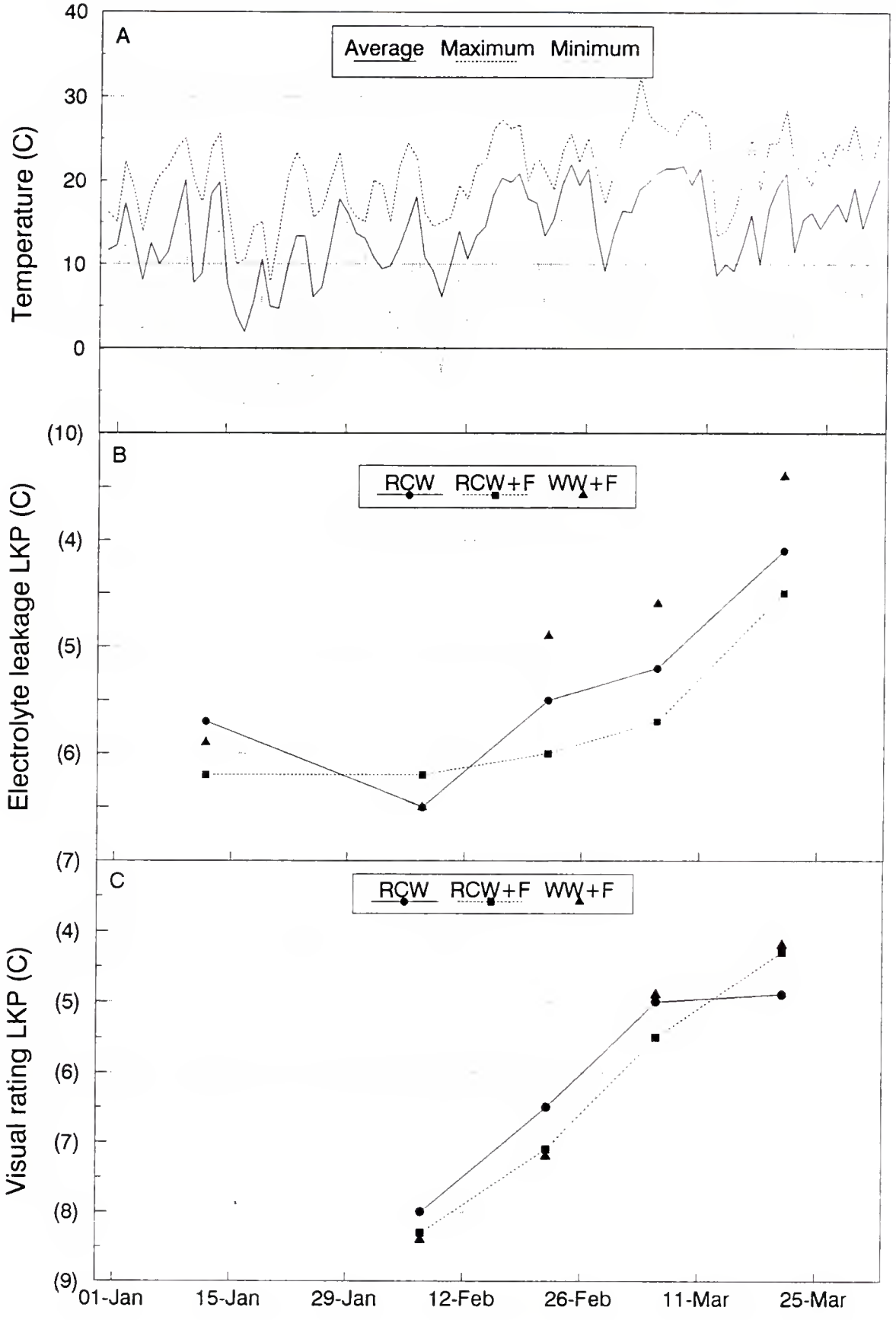
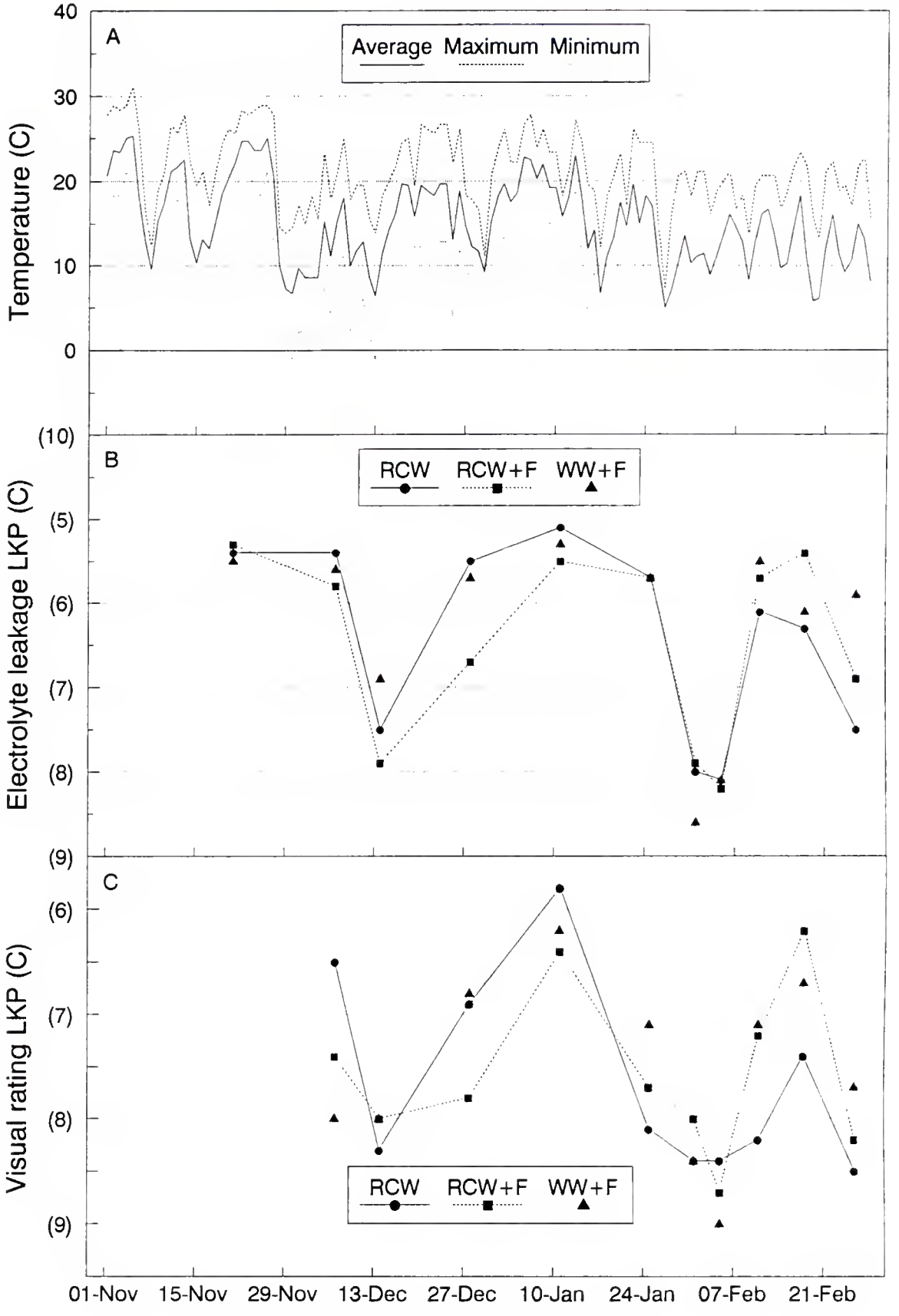

A
Average Maximum Minimum
Temperature (C)
40
30
20
10
0
(10)
B
RCW RCW+F WW+F
Electrolyte leakage LKP (C)
(4)
(5)
(6)
(7)
C
RCW RCW+F WW+F
Visual rating LKP (C)
(4)
(5)
(6)
(7)
(8)
(9)
01-Jan
15-Jan
29-Jan
12-Feb
26-Feb
11-Mar
25-Mar

Fig. 6.2. Average, maximum and minimum daily air temperatures (A), Leaf killing point determined by the electrolyte leakage method (B), Leaf killing point determined by the visual rating method (C), in 1992-93. RCW = 2.3-2.6% N, RCW+F = 3.0-3.1% N and WW+F = 3.0% N. RCW = simulated reclaimed wastewater; F = N-K fertigation; WW = well water.


A
Average Maximum Minimum
Temperature (C)
40
30
20
10
0
(10)
B
RCW RCW+F WW+F
Electrolyte leakage LKP (C)
(5)
(6)
(7)
(8)
(9)
C
Visual rating LKP (C)
(6)
(7)
(8)
(9)
RCW RCW+F WW+F
01-Nov 15-Nov 29-Nov 13-Dec 27-Dec 10-Jan 24-Jan 07-Feb 21-Feb

1983, Wiltbank and Oswalt, 1984) and the acclimation-deacclimation patterns observed here are similar to those observed by others. Leaf freeze hardiness increased after 2 weeks of continuous hardening temperatures of 10C for 'Valencia' orange trees in a growth chamber (Yelenosky, 1978). Likewise, leaf freeze hardiness of field grown citrus trees appeared to respond about 2 weeks after air temperatures were below 10C (Wiltbank and Oswalt, 1983). In addition, leaf freeze hardiness increased as air temperature below 10C increased (Young and Peynado, 1965; Rouse and Wiltbank, 1972). Likewise, LKPs from this experiment were within ranges typical of grapefruit leaves (Gerber and Hashemi, 1964; Wiltbank and Oswalt, 1983; Young and Peynado, 1965). Young and Peynado (1965) found that leaf freeze tolerance decreased within 1 week of 23/18C day/night temperatures in a controlled environment. Leaves from all treatments in this experiment and other field grown citrus trees appear to deacclimate at a slower rate than trees in controlled environments, but lower night temperatures in the field vs. controlled environment studies may have contributed to the slower rate of deacclimation. Leaf N concentration had minimal effects on acclimation, but high leaf N levels (>3.6%) during deacclimation in the spring decreased freeze hardiness of citrus leaves as observed for leaves from the WW+F trees in March 1992. In 1992-93 all leaves deacclimated at a similar rate, however, the WW+F leaves did not have the high levels of leaf N (> 3.6%) as in 1991-92. Although leaves from the RCW

trees were N deficient (<2.0%), there were no apparent differences in freeze hardiness during acclimation.

Tree freeze damage at air temperatures of -6.5C (Expt. 2)

Visual ratings of freeze damage in Expt. 2 were made on 11 Feb. 1992 a few weeks after minimum air temperatures reached -6.5C with temperatures ≤ 6.0C for 3 h on 17 Jan. 1992. Whole tree evaluations from two independent evaluators showed that the RCW trees had the greatest freeze damage followed in sequence by the RCW+F and WW+F trees (Table 6.5). Leaf loss from the fall flush was significantly less for the WW+F trees compared to the RCW and RCW+F trees (Table 6.5) Leaf tissue analysis following the freeze revealed that the RCW trees had deficient leaf N levels (2.0%) compared to 2.3% and 2.4% leaf N for the RCW+F and WW+F trees, respectively. Increased leaf and tree damage has also been reported for citrus trees with deficient leaf N levels (Koo, 1985a; Sharples and Burkhart, 1953; Smith and Rasmussen, 1958). In addition, the RCW trees had significantly higher leaf P levels (0.23%) than the RCW+F (0.15%) and WW+F trees (0.16%) (Table 6.6). Spencer (1958) found an increase in freeze damage for 'Ray Ruby' grapefruit trees as the rate of phosphate fertilizer increased. However, Smith and Rasmussen (1958) observed no effect of leaf P levels on freeze damage of 'Pineapple' orange trees. The combination of deficient leaf N and high leaf P may be partly responsible for the increased leaf damage for the RCW trees.

Table 6.5. Visual ratings of 'Redblush' grapefruit trees following minimum air temperatures of -6.5C, on 17 Jan. 1992.[z]

Treatments[y]	Visual rating[x]	Leaf loss rating[w]
Water source		(%)
RCW	3.3	54
RCW+F	2.5	44
WW+F	1.6	18
Significance		
Water source	***	***
Contrasts		
RCW vs RCW+F	*	NS
RCW vs WW+F	***	***
RCW+F vs WW+F	***	***

[z] Numbers represent the means of 30 trees/treatment.
[y] RCW = simulated reclaimed water; F = N-K fertigation; WW = well water.
[x] Visual rating of freeze damage from 0 (no damage) to 5 (≥ 75% damage). Ratings were taken on 11 Feb. 1992. Visual ratings were made by two individuals.
[w] Leaf loss ratings were made on three separate final flush shoots.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 6.6. Leaf tissue analysis of 'Redblush' grapefruit trees following minimum air temperatures of -6.5C on 17 Jan. 1992.[z]

Treatments[y]	N	P	K	Ca	Mg
Water source	(% dry wt)				
RCW	2.0	0.23	1.2	2.3	0.26
RCW+F	2.3	0.15	1.0	1.9	0.24
WW+F	2.4	0.16	1.1	2.0	0.20
Significance					
Water source	***	***	**	***	***
Contrasts					
RCW vs RCW+F	***	***	**	***	**
RCW vs WW+F	***	***	NS	***	***
RCW+F vs WW+F	NS	NS	NS	NS	***

[z] Numbers represent the means of 10 leaves/tree and 30 trees/treatment. Leaf samples were collected on 11 Feb. 1992.
[y] RCW = simulated reclaimed water; F = N-K fertigation; WW = well water.
[NS,*,**,***] Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

The difference in freeze damage for the RCW+F and WW+F trees is difficult to explain based solely on leaf tissue nutrient levels. Leaves from the RCW+F and WW+F trees had similar leaf N, P, K and Ca levels (Table 6.6). However, leaf Mg levels were deficient (0.20%) (Koo et al., 1984) for the WW+F trees, and in the low range (0.24%) (Koo et al., 1984) for the RCW+F trees which received greater leaf damage (Table 6.6). This contrasts with observations that Mg deficient trees were more severely freeze damaged than trees receiving Mg fertilizer (Lawless, 1941).

Freeze hardiness has also been associated with tree vigor. The RCW+F trees were significantly larger and more vigorous than the WW+F trees (Chapter V, Expt. 2). It has been observed that healthy vigorous trees survived freezing temperatures better than unhealthy, poorly growing trees (Koo, 1985a; Lawless, 1941; Spencer, 1960). Conversely, highly vigorous trees may not stop growing or acclimate at the same rate as less vigorous trees (Hume, 1956; Husain and Cooper, 1958). The difference in growth and development for the RCW+F and WW+F trees may have accounted for the increase in freeze damage, especially in light of the similar leaf nutrient levels.

Results from Expt. 1 indicate that leaf N levels generally had no effect on leaf freeze hardiness as the leaves acclimated. However, high leaf N (>3.6%) may decrease freeze hardiness during deacclimation. Both LKP methods produced similar trends in the data; however, the electrolyte leakage method resulted in LKPs about 1C higher than from the visual rating method.

In Expt. 2, leaf freeze hardiness was decreased at deficient leaf N levels (2.0%) compared to that at optimum levels. In addition, trees having similar leaf N levels were damaged to varying degrees which may be a result of differences in tree vigor. Possibly the many contradictory reports concerning leaf N and freeze hardiness resulted from difference in degree of acclimation and deacclimation. High N levels may increase freeze hardiness at maximum acclimation, yet might decrease hardiness during deacclimation.

CHAPTER VII

CONCLUSIONS

Irrigation and fertilization are two important practices for mature, reset, and young citrus trees in Florida. The use of reclaimed wastewater can supply citrus trees with water for irrigation and also plant nutrients reducing fertilization. The impact of reclaimed wastewater used as an irrigation and fertilizer source for citrus is essential to the safe and efficient use of reclaimed wastewater for irrigation of citrus trees.

The first part of this research demonstrated the influence of reclaimed wastewater on growth, development and production of mature 'Redblush' grapefruit trees. Trees receiving low (23.1 $mm \cdot wk^{-1}$) and moderate (30.7 $mm \cdot wk^{-1}$)-reclaimed wastewater were the most vigorous. Likewise, yield was greater for trees receiving low and moderate levels of reclaimed wastewater for all three years. Leaf tissue analysis indicated no detrimental effects from the use of reclaimed wastewater, however, leaf Na and B levels were increased but were below toxic levels. Fruit growth and development was similar for 2 of the 3 years, but reclaimed wastewater increased fruit size, fruit and juice weight in

the final year. Likewise, fruit quality TSS, TA and TSS:TA ratio varied depending on the season, however, trees receiving reclaimed wastewater fruit quality tended to improve. Peel thickness was similar regardless of treatment. Reclaimed wastewater not only increased weed growth in areas where trees had been removed or resets planted, but under mature tree canopies. Changes in weed management practices to low solubility herbicides or increased applications may be required when using high rates of reclaimed wastewater. Heavy metals levels in the applied reclaimed wastewater were low or non-detectable and are therefore of little concern. The results of effluent analysis for enteric viruses found < 0.003 PFU/liter, indicating that reclaimed wastewater meets safety standards for workers and consumers. These results suggest that reclaimed wastewater can be used at rates up to 30.7 $mm \cdot wk^{-1}$ to irrigate mature citrus trees on flatwood soils when adequate drainage is provided.

The second phase of this research was to evaluate the effects of reclaimed wastewater on reset 'Marsh' grapefruit trees. Reclaimed wastewater at low (19.0 $mm \cdot wk^{-1}$), moderate (25.4 $mm \cdot wk^{-1}$), and high (31.7 $mm \cdot wk^{-1}$) rates provided adequate irrigation for reset tree growth and development, but results were similar to those of trees receiving canal water. Although leaf Na and B levels were increased in trees receiving reclaimed wastewater compared to trees receiving canal water, concentrations were below toxic levels with no deleterious effects on tree growth. Weed growth increased as rate of reclaimed

wastewater increased. The increased weed growth may require changes in herbicide programs and increase initial production cost for resets irrigated with reclaimed wastewater.

The purpose of the third part of this research was to determine the effects of reclaimed wastewater on young 'Redblush' grapefruit trees. Trees receiving reclaimed wastewater plus fertigation were more vigorous than trees receiving reclaimed wastewater plus granular fertilizer, well-water plus fertigation, and reclaimed wastewater alone. Reclaimed wastewater alone did not provide adequate nutrition for young tree growth as trees showed symptoms of N deficiency and were less vigorous. Although trees irrigated with reclaimed wastewater had higher leaf Na and B concentrations, levels were below toxic concentrations. In one experiment, 3-year-old trees receiving reclaimed wastewater plus fertigation had higher yields than trees receiving well water plus fertigation and reclaimed wastewater alone.

The objective for the final part of this research was to determine the effects of leaf nutrient levels on freeze hardiness of young 'Redblush' grapefruit trees. Leaf N levels did not influence acclimation, however, high leaf N levels (>3.6%) may increase freeze sensitivity in the spring during deacclimation. In another experiment, trees with deficient leaf N levels (2.0%) were more freeze damaged and less vigorous than trees with low leaf N levels (2.3-2.4%). However, trees with similar low leaf N levels (2.3 and 2.4%) had different degrees of freeze damage with the most vigorous trees more severely

damaged than the less vigorous trees which both had similar leaf N levels. These results indicate that freeze hardiness may be a function of tree vigor more than actual leaf N levels. Further research is necessary to evaluate the effects of leaf N levels on freeze damage particularly during deacclimation in the spring.

These studies suggest that reclaimed wastewater can be safely and efficiently used to irrigate mature, reset, and young citrus trees. Reclaimed wastewater reduced fertilization requirements and costs for mature citrus trees, however, young citrus trees required supplemental fertilization to achieve optimum tree growth. Changes in weed management may be necessary when using high rates of reclaimed wastewater, however, increases in herbicide costs should be offset by reduced costs of fertilization and increased yield over the life of the tree. Heavy metals, salinity and enteric viruses were below levels which are considered potentially detrimental to tree growth or worker safety at this location. Caution should be taken in interpreting these results as reclaimed wastewater, soil types and drainage patterns may be substantially different at other locations.

APPENDIX

APPENDIX A.

Monthly historical and 1991-93 rainfall and temperature data for Vero Beach, Fla.

Month	Rainfall (mm)				Temperature (°C)			
	[z]	1991	1992	1993	[z]	1991	1992	1993
January	62	177.5	33.3	160.3	16.6	19.4	15.8	19.8
February	73	146.3	85.3	72.1	17.0	17.8	18.1	16.6
March	77	201.9	23.1	364.2	19.6	20.0	18.7	18.3
April	66	134.4	64.0	46.5	22.1	23.4	20.9	20.0
May	112	113.5	22.4	146.1	24.6	25.4	22.5	23.3
June	166	150.1	481.3	76.2	26.3	26.1	25.6	26.1
July	146	334.1	71.6	55.1	27.3	26.6	27.7	27.5
August	137	252.5	157.5	16.5	27.4	27.1	26.3	27.2
September	202	134.6	120.9	46.0	26.8	26.4	26.3	26.6
October	151	138.4	74.7	9.9	24.0	24.0	23.3	24.5
November	65	18.8	103.1	54.4	20.5	19.6	21.9	21.4
December	50	13.2	36.8	0.5	17.4	18.9	18.3	19.2

[z] Monthly averages from 1951 to 1980 as recorded by the U.S. Weather Bureau.

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BIOGRAPHICAL SKETCH

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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